CAPE OF GOOD HOPE.

DEPARTMENT OF AGRICULTURE.

ELEVENTH

ANNUAL REPORT

OF THE

GEOLOGICAL COMMISSION.

1906

Presented to both Houses of Parliament by command of His Excellency the Governor.

1907.

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ELEVENTH

Annual Report of the Geological Commission,

1906.

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Geological Commission of the Colony of the Cape of Good Hope.

1906.

MEMBERS OF THE COMMISSION.

The Hon. JOHN XAVIER MERRIMAN, M.L.A.

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SCIENTIFIC STAFF.

Director—
ARTHUR WILLIAM ROGERS, M.A., F.G.S.

Geologist—
ALEX. L. DU TOIT, B.A., F.G.S.

Geological Commission
South African Museum,
Cape Town, 21st February, 1907.

SIR,

I have the honour to forward the Annual Report of the Geological Commission for the year 1906.

Steady progress has been made with the general geological survey of the Colony and additions to the map have been published. It is gratifying to know that in scientific circles the work under the charge of the Commission is much appreciated.

The Commission takes the opportunity of recording its sense of the good work done by the Director, Mr. A. W. Rogers and his assistant Mr. A. L. du Toit, who have displayed the greatest possible interest in the duties committed to them.

A copy of the financial statement duly audited is appended. The Commission have always had in view the financial position and have often felt obliged to curtail expenditure in several directions in which it might have been incurred with advantage.

I have the honour to be,

Sir,

Your obedient Servant,

JOHN X. MERRIMAN,
Chairman Geolog. Comm.

The Hon. the Secretary
for Agriculture.

GEOLOGICAL COMMISSION.

Director's Report for the Year 1906.

During the past year only two men have been engaged in field work, but they have had all the necessary means of transport.

The work done was almost entirely confined to the country north of the Orange River. Mr. du Toit worked east of the Kaap Plateau from the northern limit of Taungs down to Hope Town. The chief features in that area are the number of volcanic pipes and the various developments of the Dwyka series. A large amount of information has been obtained on both these subjects. Though it is not possible to carry out such an exhaustive mineralogical and chemical examination of the contents of the pipes as they deserve, the results of Mr. du Toit's field and office work are important additions to previous knowledge. The thanks of the Commission are due to Mr. A. F. Williams, General Manager of De Beers' Consolidated Mines, for the facilities given to Mr. du Toit in his work on the properties belonging to that Company. Considering how frequently the eastern part of Griqualand West has attracted the attention of geologists from the time of the first discovery of diamonds, it is surprising how much new information has been got concerning the geology of the valley of the Vaal River. Some of this ground, however, was very carefully examined by G. W. Stow, in 1874 and 1875, on behalf of the Griqualand West Government,* but his work was never published, and Mr. du Toit has not had the advantage of consulting it. Mr. du Toit's work has made clear the relation of the pre-Karroo sedimentary rocks and lavas exposed in the Kimberley shafts to the similar rocks found elsewhere in Griqualand West.

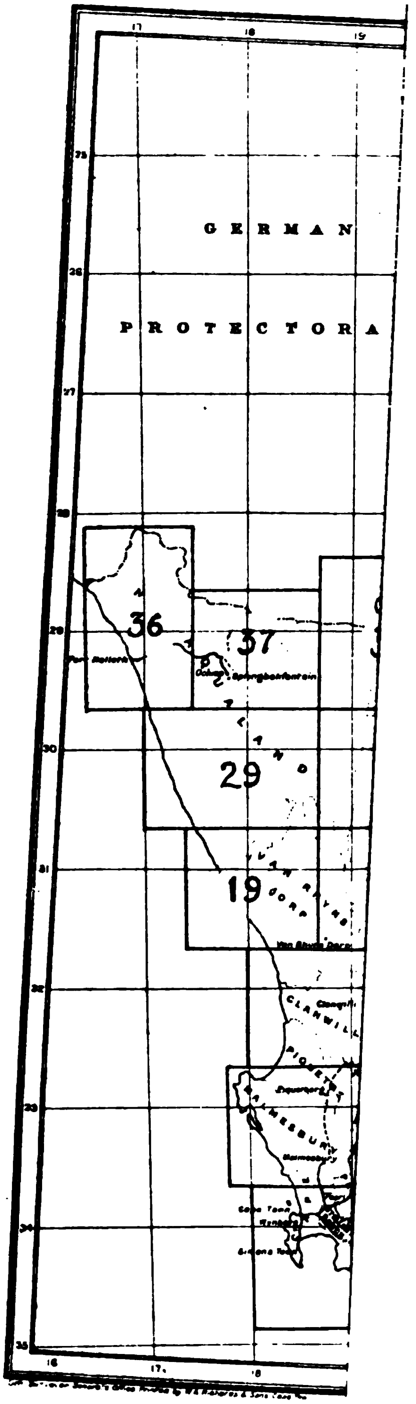
* "Correspondence . . . on . . . the geological survey of Griqualand West," Parliamentary paper A. 88. Cape Town, 1881.

My work lay west of the Kaap escarpment. The mapping of the great dolomitic limestone plateau was confined to the immediate neighbourhood of the four routes along which I travelled to and from the Kuruman district. The peculiar nature of the plateau and the number of unoccupied farms combine to make the observer's precise position often difficult to determine without spending more time there than seemed desirable. In general the geology of that area is simple, but the country is traversed by dykes of igneous rocks which are of importance in connection with water supply. The mapping of all these dykes will take a long time, but should be undertaken at no very distant date. The greater part of the work consisted in mapping rocks younger than the Campbell Rand series as far to the west as the Langebergen, and the most important result is the determination of the succession and nature of the rocks forming the Matsap series and their relation to the underlying rocks of the Transvaal system.

No large maps have been drawn for publication in this Annual Report; the reason is that a part of the area described is contained in Sheet No. 45 of the coloured map (3.8 miles to the inch), which will be issued before this Report, and a further large portion of it will be represented on Sheets 42 and 46, which may be expected before the end of the year. It is thought that under these circumstances the time which would be occupied in drawing up maps for this Report and the money required for their reproduction might be saved.

During the present year the survey will be carried on in country adjoining that mapped last year, and it is hoped that almost the whole area enclosed by the Molopo, Orange River, and the O.R.C. boundary will be completed at the end of this year.

The first coloured sheet issued apart from the Annual Reports was published in August last; two more have since been issued, and a fourth is nearly ready. These maps are on the scale of 1 inch to 1,600 Cape roods or 1 : 238,000. This scale will be adhered to for the


GERMAN
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greater part of the Colony, but sheets 47–52 and perhaps 43 and 44 may be published on a smaller scale, 1 inch to 2,000 Cape roods (4.69 miles) or 1:297,500. The field work in that region is done on this scale, and it is useless to reproduce the results in a manner which can only magnify errors.

Various circumstances have made it undesirable to carry on the survey regularly from the south-western corner of the Colony towards the north and east, and the sheets of the coloured map will be issued without adherence to a regular order. The attached map shows the system of numbering adopted for the different sheets.

It is desirable that maps of this kind should be accompanied by a descriptive text, as is the case with the maps issued by several foreign surveys. In our case, however, this cannot be done at the present time; the preparation of the text would take more time than can be spared from the field work, and the cost has to be considered. The maps, moreover, cover ground which has been more or less fully described in the Annual Reports issued since 1896, and in future an attempt will be made to keep the issue of maps up to date as regards the areas described in successive Annual Reports.

The Palæontological work based on the Survey collections is progressing. Mr. Henry Woods' memoir on the Pondoland Cretaceous fossils is printed, and is now being issued.

The following papers written by the staff were published in 1906:—

"The Stormberg Formation in Cape Colony," by A. L. du Toit, British Association Report (Cape Town meeting), 1906.

"The Campbell Rand and Griqua Town series in Hay," by A. W. Rogers, Trans. Geol. Society of S.A., 1906.

"Underground Water in South-eastern Bechuanaland," by A. L. du Toit, Trans. S.A. Phil. Society, 1906.

ARTHUR W. ROGERS.

GEOLOGICAL COMMISSION.

General Abstract of Receipts and Disbursements for the Year ending 30th June, 1906.

		£	s.	d.
To Balance 1st July, 1905		160	5	1
„ Government Grant		2,000	0	0
„ Sale of Horse		20	0	0
„ Municipal Fees—				
East London ...	£36 14 3			
Cape Town ...	6 6 0			
		43	0	3
„ Advances (current) repaid by Vouchers ...		260	0	0
		£2,483	5	4

	£	s.	d.	£	s.	d.
By Salaries	1,000	0	0			
„ Allowances, Personal	293	1	6			
„ do. Horse	26	12	0			
„ do. Cycle	9	14	0			
„ Railway Fares and Carriage ...	82	15	9			
„ Cart, Hire	8	9	6			
„ Postages	6	17	10			
„ Printing	66	6	2			
„ Books and Magazines	55	16	7			
„ Grazing for Oxen	7	0	0			
„ Analyses...	5	14	0			
„ Description of Specimens	20	0	0			
„ Rock Sections	9	12	9			
„ Horse Purchase Loss	39	15	0			
„ Oxen and Wagon	196	0	0			
„ Town Council Fees paid to Staff ...	43	0	3			
„ Shipping Charges	2	0	6			
„ Furniture and Equipment	86	6	8			
„ Boys' Wages	44	11	2			
„ do. Food	19	12	2			
„ Miscellaneous	4	3	3			
				2,027	9	1
„ Advances made				260	0	0
„ Balance as per Cash Book				195	16	3
				£2,483	5	4

THEODORE MACKENZIE, Secretary.

I certify that the above Account has been examined under my directions and is correct, and that the balance agrees with that shown in the Bank Pass Book.

WALTER E. GURNEY,
Controller and Auditor-General.

Control and Audit Office, 14th January, 1907.

GEOLOGICAL SURVEY

OF

PARTS OF BECHUANALAND AND GRIQUALAND WEST.

BY

A. W. ROGERS.

GEOLOGICAL SURVEY

OF

PARTS OF BECHUANALAND AND GRIQUALAND WEST.

By A. W. Rogers.

I. Introduction.

The country described in the following pages lies between the escarpment of the Kaap Plateau and the Langebergen, and includes a small area lying north of the Plateau.

The rocks on or near the surface in this district belong almost entirely to the Ventersdorp, Transvaal, and Matsap formations lying upon a floor of granite and schists (Kraaipan series), but this floor is only exposed at the extreme northern end of the area. There are no inliers of the basement rock. The covering of later rocks was folded in pre-Dwyka times into arches and troughs; the most important line of folds is that which forms the Langebergen, a wide arc of low mountains rising at the most some 2,000 feet above the country flanking them and concave to the west. All the other folds lie more or less parallel to this curved range, but the rocks involved in them are less closely folded. The chief of these eastern folds is that which gives rise to the Kuruman-Asbestos range, the eastern limb of a wide trough. Faults of sufficient importance to shift the outcrops considerably are very few; one of them, the Paling fault will be described below, another which passes through Takwanen is briefly mentioned, and a third traverses the base of the Transvaal system near Takoon. The two latter have not yet been fully traced.

East of the Kuruman range lies the Kaap Plateau, a region of very gently inclined strata. The earth movements which produced the western ranges scarcely affected the eastern part of the district.

Though in times long past this area must have been characterised by much greater contrasts between mountains and low ground, it is to-day a country of moderate relief; the plains are now more extensive than the hilly country. This general levelling is the result of two distinct periods of denudation, the first is of pre-Karroo and Dwyka age, and the second belongs to post-Karroo times. At present the country is being levelled up owing to the fact that the agencies of transport

are not equal to the task of removing from the district a large part of the rock debris formed within it, so that the valleys generally are being filled up. This state of affairs is responsible for the fact that surface deposits of more or less recent age form an important section of the rock groups dealt with here.

The formations that appear at the surface are:—

Recent and Superficial Deposits.—Sand, gravel, surface limestones, quartzites, and ironstone.

(Great Unconformity.)

Dwyka Series.—Glacial boulder beds, shales.

(Great Unconformity.)

Matsap Series.—Upper; quartzites and sandstones.
Middle; quartzites, lavas, volcanic breccias and tuffs, and conglomerates.
Lower; quartzites, slates, and conglomerates.

(Unconformity).

Transvaal System

Griqua Town Series:—
Upper; jaspers, limestones, and phyllites.
Middle, or Ongeluk group; volcanic rocks and jaspers.
Lower; jaspers, cherts, sandstones, quartzites, glacial boulder beds, and thin limestones.

Campbell Rand Series—
Limestones and dolomitic limestones, cherts, sandstones, quartzites, and a band of lavas in the north-east.

Black Reef Series:—
Quartzites, conglomerates, arkose, shales and thin limestones.

(Slight Unconformity.)

Ventersdorp System.

Pniel Series:—
Lavas and breccias of intermediate composition, thin flagstones.

(Unconformity).

Zoetlief Series:—Acid lavas.

(Great Unconformity.)

Kraaipan Series:—
Magnetite-schist and slates.

(Great unconformity?)

Granite and gneiss.

Intrusive rocks of various kinds, but not acid varieties, occur in these rock groups, except the Recent and Dwyka.

Little work of a purely geological kind had been done in this area previously to this survey. G. W. Stow's paper[1] and a recent one by G. G. Holmes[2] are the only papers of importance, though brief references to the rocks are to be found in several books of travel, especially those by Lichtenstein, Burchell, Backhouse, Livingstone, and Fritsch, as well as in Penning's "Gold and Diamonds," 1901.

II. THE GRANITE AND GNEISS.

These rocks appear to be the oldest seen in the district. They only occur on the northern edge of it from Keang Kop eastwards as far as Hartebeest Laagte and England. This area was the northern limit of my work, and but few observations were made on the granite; the rocks have not yet been studied in thin section.

The character of the upper surface of the granite will be described in connection with the overlying formation, the Black Reef series, between Keang Kop and Takoon. From Takoon eastwards as far as England the amygdaloid and compact diabase lavas of the Ventersdorp group crop out near the granite, though the junction has not been seen. A bore hole on Hassforth, after passing through the diabase lavas, entered the granite without the intervention of other rocks. On Hartebeest Laagte, quartz-porphyries crop out between the granite and the diabase lavas on England, but no section through the junction was seen.

On the Motiton Reserve (which includes Takoon) the granite crops out in large masses near its southern boundary, and it is well exposed in the bed of the Mashowing River. The bulk of the rock is a pink biotite gneiss, and the strike of the foliation planes is between 10° and 25° east of north, but there are many large groups of outcrops of pink granite in which no foliation is observable. These massive granites have occasional porphyritic crystals of orthoclase in them, and are traversed by bands of grey biotite-gneiss and by veins of pegmatite, which generally lie parallel to the gneiss bands, but at places cut through them in various directions.

East of Takoon the granite crops out south of the diabase hill on which the Trigonometrical beacon stands, but north of that hill the outcrops become scarce. From this place to Hartebeest Laagte almost all the granite occurrences were noted from wells alone. On Zout Pan, however, there are outcrops in the pan which gives the place its name. The rocks are very similar to those on the Mashowing and at

1 Quart. Journ. Geol. Soc., London, Vol. XXX., p. 581.
2 Trans. Geol. Soc., S.A., Vol. VII., p. 130, 1905.

Motiton, grey gneiss, pink gneiss, and massive granite, and pegmatites. The foliation planes are directed from N. 10° E. to N. 35° E. These outcrops project a foot or so above the flat floor of the pan, and the rocks are not deeply weathered; fresh specimens can be broken off without difficulty. The ground rises some 100 feet within half a mile of the edge of the pan, and on this slope there are shallow wells which go through the superficial deposits into the granite, and the granite is seen to be weathered to a distance of ten feet from its surface, the deepest exposed section at the time of my visit. These exposures all lie several feet above the floor of the pan.

III. The Kraaipan Formation.

There is a low, red, sand-covered ridge on the farms Hamburg and Kameel Rand; it lies nearly east and west, and it is continued west of Kameel Rand, though that part of its course has not yet been examined. On the two farms mentioned, there are two outcrops of magnetic schists and quartzites on the top of the ridge; on Kameel Rand three prospecting holes have been dug, and from these, together with the neighbouring outcrops, the following section was drawn:—

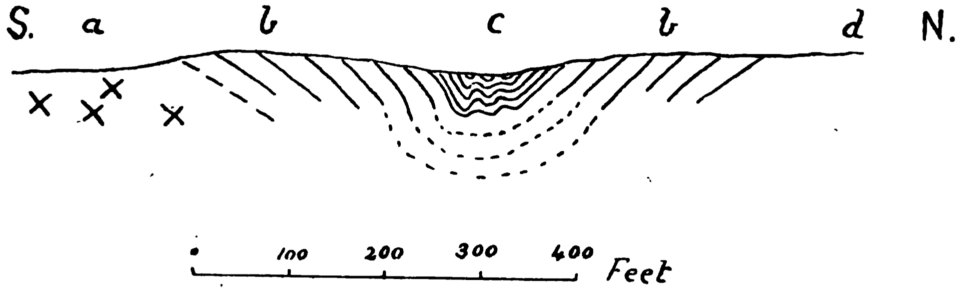


Fig. 1.—Section from south to north through a part of Kameel Rand to show positions of the Kraaipan outcrops. *a.* gneiss, only seen in loose fragments. *b.* magnetic schists and thin quartzites. *c.* crumpled and weathered finely micaceous slates. *d.* sand-covered ground.

On the south side of the ridge a few pieces of coarse gneiss were found in the surface soil, but no outcrops of this rock were seen; the nature of the soil between the ridge and the amygdaloidal diabase of the southern part of Kameel Rand is similar to that covering the granite and gneiss in the Mashowing Valley; quartz and dull felspar grains are abundant, and there can be no doubt that gneiss lies immediately south of the magnetic schist or other rock belonging to the same series. The contact is not exposed, and is not likely to be seen at any point along this ridge unless an artificial exposure happens to cross it.

The lowest beds of the Kraaipan series which I saw are rather coarse quartzites containing much magnetite, which is cleaved in such a way as to impart a distinct schistosity to the rock The magnetite is more abundant in some layers than in others, and the planes of schistosity are parallel to these layers in the specimens examined. The magnetic quartzites first dip northwards, but the strike varies between E. 30° S. and E. 10° N. in the small area over which they are exposed. The section seen in one of the prospecting trenches reveals many small dislocations which are too small to be shown on the section in Fig. 1. The quartzites are not closely folded as are the greenish-brown slates exposed in a cutting just to the north of them. Those slates are deeply weathered, but were evidently fine grained micaceous slate before they were altered by the weather. They lie in a syncline, for to the north of them appear the same magnetic quartzites that crop out to the south, but with a southerly dip.

Both the quartzites and slates are traversed by small quartz veins which were the object of the prospecting operations. Up to the present time, as far as I am aware, no quartz veins of considerable size or constancy have been found in this ridge.

The magnetic quartzites and schists of Kameel Rand are so like some of the rocks in the Kraaipan series described by Mr. du Toit in the Annual Report for 1905, that there is little room for doubt that they belong to the same group. At the end of my journey I went to Kraaipan and examined some of the sections and outcrops of the Kraaipan series. The magnetic rocks of the ridge near the station are of quite the same nature as those at Kameel Rand, and they only differ from the latter in being finer in texture generally, though coarse grained rocks are present. The exposures near Kraaipan, however, are on a much larger scale than those at Kameel Rand, and the junction with the gneiss is seen there. The mica-schists at the base of the Kraaipan series in the railway cutting near the station are not represented by any visible rocks at Kameel Rand, though the decomposed micaceous slates lying above the magnetite schist at the latter locality are not unlike some of the basal schists at Kraaipan. The Kraaipan section, as described by Mr. du Toit, shows no evidence of the intrusive character of the granite.

At a short distance north-eastwards from the cuttings on Kameel Rand, there is a pan in which several outcrops of the amygdaloidal diabase appear. These outcrops certainly belong to the lavas of the Ventersdorp series, and they were traced north-eastwards across Hamburg. They must overlie the Kraaipan formation in this neighbourhood, though a section showing the relation was not found.

IV. The Ventersdorp System.

Under this term will be included two distinct volcanic groups, a lower acid series of lavas and an upper more basic series. This arrangement was adopted in the 1905 Report by Mr. du Toit as a result of his survey of the area lying just to the east of that which is being described here. Until the committee appointed by the British Association to consider and fix upon a uniform nomenclature for the larger South African rock groups has made its report, the term Ventersdorp system can be used without further discussion; and, as to the propriety of including the two sub-groups in that series, it is evident that convenience recommends such a course unless the break between the two sub-groups proves to be too great. There is certainly a considerable unconformity below the upper or Pniel beds, and the lower more acid lavas, the Zoetlief beds, but at present there is insufficient reason to make two large groups or systems, where one will include all the volcanic rocks lying below the Black Reef quartzites and resting upon a surface of gneiss, granite, or steeply-inclined sedimentary rocks of the Kraaipan or other older formation.

The possible relationship of the group of acid lavas in Vryburg to the Beer Vley volcanic series cannot be decided upon yet. Beyond the fact that the lavas of both these groups are more acid in composition than the amygdaloidal diabases of the Pniel series, there is no close resemblance between them.

A. The Zoetlief Series.

These beds in the area north-west of Vryburg, described by Mr. du Toit in last year's report, consist of arkose and quartzites at the base, more or less acid types of lavas, and a second group of sedimentary rocks at the top. A small area occupied by this series is included in the district under consideration. The acid lavas were first seen on Hartebeest Pan, where they crop out on sandy, rising ground at a considerable distance from the nearest granite or gneiss exposures to the west. The arkose and quartzite below the lavas are not exposed. On Kaffir Pan there is a considerable variety of acid porphyritic rocks, but they only crop out in small patches in the pan and near it, and no distinct bedding planes or divisions between flows were detected. In a small quarry on the same farm there is one nearly horizontal parting between a lighter-coloured porphyry above and a darker red porphyry below. In the immediate neighbourhood of this quarry a small cutting has been made, and a band of cherty quartzite eight inches thick exposed; the sedimentary rock probably lies above the pink porphyry in the quarry, and other outcrops of porphyry are seen above the level of the quartzite.

The lavas vary considerably in the amount of quartz present as porphyritic crystals or corroded crystals, and in the relative proportions of the felspar and quartz crystals; the colour also varies, the most usual matrix is a light red felsite, but almost white, pale green, and blue felsitic rocks were seen on Kaffir Pan, Harbro, Klip Fontein, and Schildpad Kuil. Ferro-magnesian constituents are not visible to the naked eye, and thin sections of the rocks are not yet available.

From England to Manchester the nearest outcrops south of the porphyries are bluish amygdaloids belonging to the Pniel series. The junction between them is not exposed, but the fact that the position of the lowest blue amygdaloids seen on Schildpad Kuil varies in level by 100 feet or more within a short distance, points to the surface of the acid lavas being rather uneven. The want of clearly-exposed divisional planes in the acid lavas near Schildpad Kuil prevents a comparison of their dips with those of the overlying Pniel lavas being made in this neighbourhood.

B. The Pniel Series.

The group of amygdaloidal lavas and other rocks lying below the Black Reef series, to which Stow gave the name of Pniel beds, has now been followed from the Vryburg area down the valleys of the Dry Harts and Vaal to the Orange River, and there is no question as to the various outcrops of amygdaloidal diabases below the bulk of the Black Reef series belonging to one group of rocks.

There is, however, some doubt as to the propriety of drawing a strong divisional line, as between two rock systems, between these lavas and associated rocks and the Black Reef series in the Vryburg area. The sections described below from Motiton and Takoon are sufficient to show that in this area the lavas and the Black Reef series are very intimately connected; and the interbedding of similar lavas with the sedimentary rocks of the Black Reef and Campbell Rand groups near Vryburg, as described in last year's report,[1] and again, from the country further west in this year's report, decidedly support this view. The great unconformity between the diabase lavas and the overlying Black Reef series in the Transvaal,[2] as shown by differences in dip in sections where both formations are exposed, does not appear to exist in the Vryburg area. The overlapping of the Black Reef series west of Vryburg is probably due to the original thinning out of the lower group westwards, and to the irregularity of the surface on which the lavas came to rest, rather than to the denudation of the volcanic rocks before the Black Reef beds were laid down.

[1] Du Toit, Ann. Rep. Geol. Comm. for 1905, p. 247.
[2] Molengraaff, Geology of the Transvaal, 1904, pp. 21 and 29.
Hatch and Corstorphine, Geology of South Africa, 1905, p. 153.

Proceeding eastwards from the western side of the Motiton Native Reserve, the first outcrop of amygdaloidal diabase, which lies between the granite and the Black Reef beds, is seen about a mile and a half east of the church at Motiton; it is partly covered by a northward projecting tongue of Black Reef beds, and a small outcrop of similar lava is seen on the eastern side of the same tongue nearly two miles further east. The junction with the overlying beds is not well exposed.

An isolated outlier of the lavas forms a hill in the fork of the Mashowing River, just west of the chief village at Takoon, but the Black Reef beds do not cap the outlier, which consists of amygdaloidal and compact diabase.

On the ridge south of the store at Takoon the amygdaloid reappears, and was followed uninterruptedly eastwards to the neighbourhood of Massouw's Kop, where Mr. du Toit's work ended in 1905.

As will be more fully described below, the base of the Black Reef series near Motiton is formed by arkose, and at Takoon a precisely similar arkose lies below the diabase lavas.

On the ridge, about half a mile south of the store at Takoon, very interesting sections are exposed. The ground on either side of the ridge is made of granite and gneiss, which also crop out at the west end of the ridge, above the right bank of the main head-stream of the Mashowing River; the ridge itself is a tongue of diabase, partly lava and partly intrusive work, projecting westwards from the main body of those rocks east of Takoon. Near the west end of the ridge, and on its north side, arkose is seen to lie below the lowest lavas, and thin beds of arkose are intercalated with lava higher up the slope of the hill. Large masses of arkose, quite irregular in shape, are enclosed in the lower and highly vesicular lava flows. On the south side of the ridge the junction is complicated by the intrusion of compact blue diabase, which sends thin veins downward along the joint planes in the granite. There is a great contrast in general appearance between the slaggy lava of the north side and the intrusive rock on the south side of this ridge, but the distinction is not easy to follow through the main body of lavas in the upper part of the ridge. On examination of the Black Reef escarpment south-east of this ridge, where a considerable area of amygdaloidal lava intervenes between the granite and the Black Reef beds, the latter were found to consist entirely of quartzites, conglomerates, and felspathic quartzites; no rock containing enough felspar fragments to be called an arkose was seen there. At the place where that tributary of the Mashowing which rises on the farm Pretoria Uplands leaves the Black Reef beds, there is a section showing white glassy quartzites belonging to the latter, resting on compact blue diabase, which cuts

across the bedding planes of the quartzite. The junction of the diabase with the granite is not visible, though only a few feet of silt-covered ground separated their outcrops in the river bed at the time of my visit. The white quartzite seen in this section is obviously part of the Black Reef escarpment, and it has a strongly marked vertical prismatic jointing near its contact with the diabase. There is here clear evidence that the diabase is intrusive, and that the peculiar glassy and brittle character of the quartzite at this spot is due to its influence. The amygdaloidal lavas are not seen in this section, and there is only room for a small thickness of arkose, if it exists here.

The interest of these sections showing the intrusive nature of the compact diabase lies in the evidence they give of the intrusive character of rock which, in less well-exposed outcrops, would have been mapped in as an integral part of the volcanic series. The intrusive rock, as seen in a hand specimen, is so like the amygdaloidal lavas that the presence of the amygdales alone distinguishes them, yet the absence of amygdales would not be sufficient evidence to decide the intrusive nature of diabase seen in more or less isolated outcrops in the volcanic group. In the country near the hill on which the geodetic beacon Takoon stands, there is a large body of compact diabase, but there is at present no clear evidence of its character. The separation of the intrusive rock from the lavas in the greater part of the area occupied by the Pniel group cannot be carried out now.

The diabase ridge on which Takoon beacon stands is partly separated from the main outcrop by a tongue of granite and gneiss exposed in the valley of a tributary of the Mashowing from Bosch Plaat and Kopjes Laagte. On the farm Bethlehem greenish-blue flagstones are quarried from about the middle of the series; the flags are used for building and fencing poles. The amygdaloidal lava is exposed at several places on the strip of country, from four to five miles wide, made of this series between Takoon and Kameel Rand, though the ground is usually covered with reddish sand, which in some prospecting pits on Hassforth are seen to attain a thickness of from 20 to 30 feet. At Kameel Rand the width of the volcanic belt decreases by one-half, and at the same time the surface slopes more steeply upwards from the probable position under the soil of the southernmost granite to the foot of the Black Reef escarpment. From Hamburg to England the volcanic belt widens, and reaches a width of ten miles. In this wide tract the rocks are not often seen; considerable areas of very flat ground, covered with grass and hard soil, mark its position. On Schildpad Kuil and between the Schildpad Kuil hills and the geodetic beacon V.c. on Bok Kraal, the volcanic beds make a low escarpment, capped for the most part by the Black Reef beds.

A section seen on the north-western slope of a hill on Schildpad Kuil is recorded here:—

Grey-green breccia forming the summit of the hill	40 feet.
Compact blue diabase	20 „
Blue amygdaloidal diabase	50 „
Grey amygdaloidal lava, more acid rock than the blue amygdaloid	4 „
Blue amygdaloid, with occasional very large amygdales	30 „

The bottom group of lavas in the above list is thicker than 30 feet; it forms the base of the hill and stretches northwards about half a mile from the hill; beyond that distance the quartz-porphyries of the Zoetlief beds crop out.

The fine-grained green flaggy beds lie above the green breccia of Schildpad Kuil; they are first seen some distance south-east of the hill, and they are overlain by a further thickness of amygdaloidal lavas. The beacon V.c. on Bok Kraal is on an outlier of the Black Reef, about 400 yards from the main outcrop of that group, and the lavas on which it rests contain chalcedony amygdales up to 12 inches in length.

The diabase lavas and associated breccias and fine-grained blue flagstones have a low dip towards the Black Reef beds in their vicinity. The angle of dip is difficult to measure with accuracy, but it never seems to exceed 5°.

The thickness of the group increases eastwards; at Motiton, as we have seen, it does not exist west of the Church and Police Camp. At Takoon beacon it is about 200 feet, rather less than over that amount. At Hassforth a borehole has been put down on the Black Reef beds, through the volcanic group to the granite; the record of the core was not available, but the owner of the farm, Mr. Hassforther, told me that about 400 feet of core like those fragments of it which I identified as belonging to the Pniel series were brought up, so the total thickness at this place probably does not exceed 400 feet. On Schildpad Kuil the whole thickness is between 300 and 400 feet. At Vryburg there are at least more than 500 feet of rock belonging to this formation.[1]

In a well on Hamburg some 40 feet of blue sedimentary rock are exposed in the Pniel series, but no conglomerates were met with. Throughout the area of Pniel beds west of Vryburg, there were no conglomerates or quartzites seen. The only coarse fragmental rocks are breccias, evidently of volcanic origin, and the blue flaggy beds.

[1] Ann. Rep. Geol. Comm. for 1905, p. 241.

Neither the sedimentary nor the igneous rocks of the Pniel group in this area have yet been examined under the microscope.

The lava outcrops throughout this area are fresh; only a very thin crust of weathered rock conceals the fresh material. Where the rock is only seen in wells or other excavations in sand-covered ground, it is always more deeply weathered. On Hassforth, where from 20—30 feet of sand overlies them, the lavas are decomposed to a depth of quite ten feet below the bottom of the sand. A similar phenomenon is noticeable in the granites of the Mashowing valley. It is doubtless due to the effect of the ground water kept in contact with the diabase for long periods by the sandy covering.

V. The Transvaal System.

That the rocks older than the Karroo formation in Griqualand West included representatives of strata developed in the Transvaal has been known for many years. In Mr. Dunn's map of 1887 a large group of beds common to the two countries is called the Lydenburg group, but its limits were not defined; this term was revived in 1904 by Dr. Passarge[1] to include the beds between the bottom of the Black Reef and the top of the Pretoria beds; in the same year Dr. Molengraaff, after abandoning the correlation with the Cape formation, used the name Transvaal system[2] for this group, and that name is now generally used. The first geologist to trace the connection between the two countries in the field, and thus to establish definitely the correlation of the Campbell Rand series with the dolomites, and of the Griqua Town series with the Pretoria beds, was Mr. G. G. Holmes.[3]

The Transvaal system in the Cape Colony will here be held to include the beds from the base of the quartzite and conglomerate above the Pniel lavas, or resting directly on still older rocks when the latter are wanting, and the top of the Griqua Town series. As a result of the past year's work, the Griqua Town series has been enlarged to include the Ongeluk volcanic beds and sedimentary rocks lying with apparent conformity on them.

A. The Black Reef Series.

This group of rocks was traced through a distance of 55 miles from the eastern of the two beacons called Keang Kop (Keang Kop A) through Motiton, Takoon, Hassforth, and Geluk to New York, where the outcrop joins the area mapped

1 Die Kalahari, 1904, p. 49.
2 The Geology of the Transvaal, 1904, p. 24.
3 Trans. Geol. Soc., S.A., Vol. VII., 1904, p. 130–132, and a map.

by Mr. du Toit in 1905. The nature and distribution of the beds in this area are given by Mr. Holmes in the paper referred to above, but some further details are here added.

The Black Reef series gives rise to an escarpment which stands out prominently east of Motiton, but becomes less conspicuous, though still the most important feature in the relief of the ground east and north-east of the Motiton Reserve, as far as Utrecht. North-east of Utrecht the escarpment is continued by the lavas of the Pniel series, rocks which also make a prominent ridge for a short distance near Takoon Kop.

The series consists of quartzites, grits, felspathic quartzites, conglomerates, arkose, shales, flaggy argillaceous quartzites, and calcareous grits. If the limit between it and the overlying Campbell Rand series be taken at the top of the highest quartzites, then the Black Reef series includes some thin beds of dolomitic limestone. Near the road leading south from Motiton to Kgatlogomo there is a section showing thin limestones, interbedded with brown-weathering quartzite, and lying below some 10 feet of similar quartzite; there are beds of calcareous grits below these limestones. The choice of a divisional line is a matter of little practical importance at present, but for the purposes of my mapping, I drew it at the top of the highest brown quartzites on the Motiton-Kgatlogomo road. It is rarely that one finds sufficient outcrops to decide the exact position of the boundary wherever the choice may lie; though by far the greater part of the distance through which the boundary was traced it might lie anywhere within 100 to 300 yards. If drawn at the top of the highest quartzites, there is more likely to be consistency in line throughout the map than if the lowest dolomite or limestone band be chosen as the limit. It is frequently the case that the neighbourhood of the boundary is marked by a slight depression, and at Mooi Fontein the large brak-water pan is in that position.

Between Keang Kop A and Motiton, and at places between Motiton and Takoon, the base of the formation lying on the granite is well exposed. In each place examined there are some feet of arkose lying directly on the granite. The arkose is over 30 feet thick over Motiton, and the change in composition through felspathic grits and quartzites to more or less pure quartzites is gradual in each section. At some spots it is difficult to find the precise limit between the granite and arkose; the granite is deeply weathered, and so also is the arkose. Pebbles of granite are not often seen in the arkose, but pebbles of vein quartz are so abundant in some layers that the rock is a conglomerate with an arkose matrix.

The arkose was not found where the Black Reef beds rest upon the Pniel series, nor was a rock corresponding to arkose, but made of diabase debris, seen in those localities. I did not find pebbles of diabase in the Black Reef conglomerates, though

chalcedony, which may have come from amygdaloidal diabase, is rather abundant, in the form of rounded pebbles. Mr. du Toit found water-worn pieces of diabase in the Vryburg conglomerates. The contrast between the contents of the basal beds on the granite and those on the diabase is very marked, however, and it occurred to me, when taken into consideration with the above-described sections at Takoon (p. 16), to indicate a rapid succession in time of the basal Black Reef beds to the underlying volcanic rocks in this area.

The junction with the Pniel series is not so frequently or so well exposed as that with the granite, but at the beacon V.c. on Bok Kraal, and on the southern part of Schildpad Kuil, the junction is seen, and the lowest beds of the Black Reef series, slightly felspathic quartzites, rest upon amygdaloid and breccia respectively at the two places.

The felspathic quartzites are a characteristic feature in the Black Reef beds, though quartzites without a sufficient quantity of felspar to be noticed by the unaided eye are equally widely distributed. The felspathic quartzites seemed to be most abundant in the western part of the area examined.

The conglomerates in this series were seen at Motiton and Takoon, where prospecting has been carried on, at Hassforth, between Geluk and Doorn Poort, Mooi Fontein, and New York. They are not regularly distributed throughout the area on one or more horizons, but are probably in lenticular layers rarely a foot thick. In four traverses between Hamburg and New York, only two outcrops of a conglomeratic rock were seen; but the rocks are not well exposed. The pebbles are of quartz, chert and chalcedony, granite, and dark slatey rock, but granite is not abundant. The matrix is quartzite, with pyrites or rusty iron ore sparsely disseminated through it. Coarse grits were seen at Motiton, Takoon, Hassforth, and Geluk; they always contain felspar fragments. The thick-bedded rocks in this series are usually strongly false-bedded. The flaggy beds are thin ripple-marked quartzites. Hard grey or blue argillaceous flagstones are occasionally interbedded with the more usual quartzites. The thin blue limestone or dolomite interbedded with the uppermost quartzites near Motiton is just like the similar rock of the Campbell Rand group, and the calcareous grit is a limestone containing a considerable proportion of quartz grains.

The dip of the Black Reef beds is southwards at angles usually less than 5° along the northern edge of the Kaap Plateau. Between Tampans Fontein and Vryburg there is a low synclinal fold, and the dips become more easterly on the west side of the syncline.

The middle of this synclinal area is traversed by a fault, with downthrow on the east side; there is an inlier of the Black Reef and volcanic rocks connected with the fault on Goedver-

wacht, Lochnagar, and the Takwanen Reserve. The structure of this inlier on Takwanen has not yet been worked out; there is a difficulty in separating the Pniel volcanic rocks from those close above the Black Reef quartzites, in the absence of numerous outcrops. This inlier will be more fully examined next season. Though the structure of the inlier is at present doubtful, there can be no question that the conglomerates exposed at several places along the western side of the "aar" north of Lochnagar belong to the Black Reef series. They have a low westerly dip under the dolomite west of the fault. The fault coincides with the "aar," which is also the position of a dolerite dyke.

B. The Campbell Rand Series.

This formation occupies almost the whole of the Kaap Plateau, and a large tract of rather similar country lying to the west of the syncline of the Asbestos Mountains, between the neighbourhood of Postmasburg and the Kathu Forest; the latter area may be called the Maremane anticline, from the large Native Reserve which lies entirely within it.

(a) The Kaap Plateau.

The Kaap Plateau is a roughly triangular area, with its base stretching from Vryburg westwards to Tsenin, on the Kuruman River, and its apex near the Orange River, at Read's Drift, an area of over 6,000 square miles. The Plateau appears to be remarkably flat to a person travelling across it in any direction, and the shallow dry valleys on its surface have so slight a slope that it is sometimes difficult to decide the direction of fall when walking in them. There are but few hills on the plateau, and these usually have gentle slopes, and do not rise more than 100 feet above the surface in their neighbourhood. Towards the western side there are a few abrupt hills in the area where chert is more abundant than in other parts of the Plateau; those hills are made of chert and limestone, *e.g.*, the hills on Pakhane, Kono or Koning, Kogel Been, and between that farm and Daniel's Kuil. North of Daniel's Kuil there are hills made by outlying masses of the Griqua Town beds; one of those is the hill called Ramaje's Kop by Stow.[1]

The highest point on the Plateau is probably the hill on which the beacon Khaw stands, 5,032 ft.,[2] and the valley of the Kuruman River below the Magistracy is probably under 3,900 feet; the edge of the Plateau between Vryburg and Campbell lies at about 4,000 feet, or slightly above that level. The difference in level, therefore, at various parts of the surface is over 1,000 feet, but they are brought about so gradually that the Plateau appears to be flatter than it really is.

[1] G. W. Stow, Q.J.G.S., Vol. XXX., p. 665.
[2] Report of the Surveyor-General for 1901, p. 9.

The inlier of the Black Reef series and volcanic rocks near Takwanen is of considerable size, quite ten miles long from north to south, yet it makes no feature on the surface, though the great contrast in character between the rocks exposed in it and the dolomitic limestone which entirely surrounds it leads one to expect a hill or belt of rising ground marking the position of the inlier.

The eastern limit of the Plateau is the escarpment trending a little west of north from Vryburg to the Griqualand West boundary near Taungs, and thence in a more south-westerly direction to the Orange River, near Read's Drift. The edge of the Plateau does not coincide with the base of the Campbell Rand series, which is found in the valley (Dry Harts, Harts, and Vaal) below, usually buried for considerable distances under the Dwyka series or recent deposits.

The surface of the Plateau is well covered with grass and bush, but over very wide areas it is extremely uneven, owing to the presence of projecting angular lumps of chert and dolomitic limestone. These rocks project a foot, or even two feet, above the soil. In other areas surface limestone appears above the soil every few feet. Generally speaking, the soil is thin; only in some of the shallow valleys and in the sandy country does the soil become thick. The pans, which are extremely numerous on the Plateau, have rock floors in most cases; in others, however, the floor is made of soft white tufaceous limestone. Towards the western side of the Plateau, especially north of Griqua Town, the Plateau becomes more sandy, and in the Kuruman area there are wide stretches of country in which there are no outcrops either of the Campbell Rand series or of surface limestones; in these tracts the limestones are met with in wells a few feet below the sand.

The surface of the Plateau usually falls slightly towards the western boundary, which is formed by the Kuruman-Asbestos range, made by the escarpment of the Griqua Town series.

With the exception of the inlier of older rocks mentioned above, the Plateau is made almost entirely of the Campbell Rand series, dolomitic limestones, cherts, and shales. The long, low, and narrow ridges called "aars," usually found to consist of white tufaceous limestone, are not infrequently seen. In many cases they are certainly due to the presence of dykes of dolerite or other igneous rock traversing the Campbell Rand series. These aars will be described more fully in that section of the report which deals with the intrusive rocks.

The Campbell Rand series in the Kaap Plateau consists mainly of dolomitic limestones with which chert is often associated. Shales occur at many places, especially towards the bottom of the series. On Mount Carmel, a farm about 15 miles north of Daniel's Kuil, there are bands of shale interbedded, with thin limestones and cherts within 40 feet of the top of the

series. These shales were searched for fossils without success, as was also the case with the shales well exposed near the base of the series at Baviaans Krantz, and near Geluk in Vryburg.

The dolomitic limestones and cherts were briefly described in the last Annual Report,[1] and there is not much new information to add about these rocks generally. A peculiar rock is sometimes met with, interbedded with the dolomitic limestones. It is an obviously oolitic rock. Thin sections cut from this oolite from an outcrop on A. 23, in the north of Hay, show that it is almost entirely composed of quartz [1606, 1606A]. The outlines of the oolite grains are not visible under the microscope. The whole is made up of small interlocking grains of quartz, the size of which varies considerably; a few grains are large enough to show the uniaxial character of the mineral. Examined in ordinary light, the sections show some brown colouring matter arranged round straight-edged areas, which are evidently sections of rhombs; in polarized light between crossed Nicols the rhombs are scarcely visible, because the areas enclosed by the straight edges are parts of adjacent quartz grains, whose boundaries do not coincide with the stained edges. The quartz within these areas is more cloudy than that outside them, owing to the inclusion of very minute black specks; in many cases there are also very small black needles, which appear quite opaque, even in the thinnest examples. These needles do not occur outside the sections of the rhombs. Both in these areas and without, the quartz encloses very minute crystals and grains of a very highly doubly refracting and colourless mineral, certainly a carbonate.

This is, without doubt, a silicified oolite, which was formerly made of carbonates. Professor R. B. Young has described such rocks from Griqualand West, together with analyses, and he pointed out that they become indistinguishable from some quartzites.[2]

The cherts are more abundant in the upper half of the series than the lower, though in some places where the passage from the Campbell Rand beds up into the Griqua Town series could be followed closely, as at Gamohaan or Kuruman Kop, and on the hillside north-west of Daniel's Kuil, chert does not occur within about 100 feet of the top of the former group. Where chert is very abundant, *e.g.*, between Daniel's Kuil and Nelson's Fontein, it often occurs in large mases which have a convex upper surface, though the dip of the overlying dolomitic limestone does not conform to this surface, but steadily maintains its uniform low angle wherever the inclination can be observed.

[1] Ann. Rep. for 1905, pp. 152–154.
[2] The Calcareous Rocks of Griqualand West. Trans. Geol. Soc. S.A., vol. x., 1906, p. 57.

These convex masses have irregular flattish hollows within, lined with quartz. They appear to lie on one and the same horizon, as Stow states in his description of them,[2] for they were seen again on the Kono Reserve, south of Kuruman, at approximately the same vertical distance from the top of the series.

Between Moroping and Kuruman village there are large masses of black chert exposed on the veld. One of these measured from 6 to 10 feet across, and made a dyke-like outcrop, traced for over 100 yards. In another case the chert formed a lump, irregularly rounded in outline, 30 feet in diameter, and projecting 6 feet from the ground.

Though much of the chert occurs in such irregular forms, which cannot have been taken at the time when the limestone was being deposited, there are bands which maintain a uniform thickness and appearance over considerable areas. One bed of finely-banded chert was traced for over 400 yards round a slight rise on Mount Carmel, and throughout that distance it is 5 inches thick.

The sections on the slopes of Gamohaan (the native name of the hill often called Kuruman Kop; on the Divisional map the name is applied to the high point on the escarpment behind on which the geodetic beacon stands) are of considerable interest. The hill is capped by an outlier of Griqua Town beds, nearly 100 feet thick. The passage from one formation to the other is undisturbed by the process of solution and collapse noted in several localities and described below. The uppermost limestones are rather thin-bedded, and are coloured with green and pink tints, thus looking different from the usual blue or grey limestone of the bulk of the series. These variously-coloured beds contain numerous spherical lumps of rusty iron ore and haematite, up to half an inch in diameter. Two layers of similar limestone were seen above the lowest beds of banded magnetic jaspers in the outlier. The grey limestone about 150 feet below the top of the series, near Gamohaan, has a peculiar spheroidal structure, only visible on weathered surfaces; it is due to the presence of concentrically-arranged layers of rock, about one-twentieth of an inch thick, of slightly different composition, which weather at different rates, and have not quite the same colour (shades of brown), due to the accumulation of iron oxides. The spheroidal shape of these structures is evident on the angular weathered blocks. In no case could I detect with a lens any such structure on a freshly-broken surface. Another peculiar structure gives rise to columns and arches on vertical sections of layers up to two inches thick, and traceable for several yards. The appearance reminded me of the Cotham limestone in the English Lias, though the columns are more regularly placed in the Gamohaan rock.

[2] Stow, *loc. cit.*, pp. 658, 659.

The spheroidal lumps of iron ores were observed in unusually coloured limestones on Mount Carmel, and again, during the previous year, on the Enkelde Wilgeboom inlier on the Orange River. In both these cases their position is within a few feet of the top of the series.

Water in the Kaap Plateau.

The dolomitic limestones of the Kaap are traversed by many narrow passages, along which water may still flow. The remarkable spring at Kuruman, which yielded, according to a measurement made by me in September 1906,[1] $5\frac{1}{4}$ million gallons a day, issues from the base of a low krantz of limestone, but it receives additions from springs which rise from the sandy

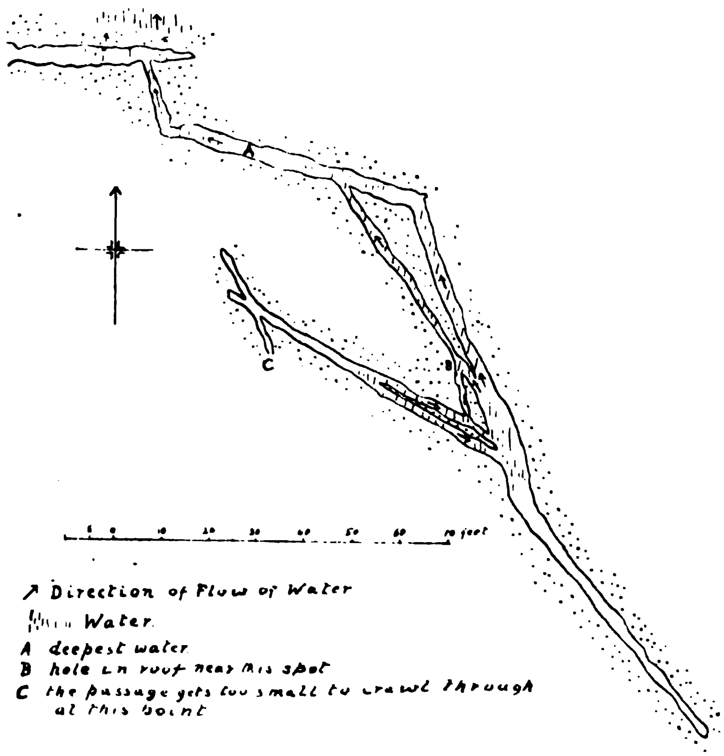


FIG. 2. Plan of Kuruman Cave.

bottom of the pool below the krantz. There is a hole on the west side of the mass of limestone forming the krantz, down which one can drop into a passage behind the krantz. A plan of the passages (Fig. 2) was made by means of a compass and

[1] The measurement was made by timing floats over 68 feet of a recently-cleaned part of the furrow on erf No. 17, some 700 yards below the drift at Kuruman.

tape, and the annexed diagram is a copy of it.[1] A considerable part of the passages is dry at the present time, and, judging from the amount of earthy matter lying on the dry floor, some considerable time may have elapsed since water flowed over these parts. Neither the floor nor the roof maintains the same level for any considerable distance. At the point marked A, the floor is lower than elsewhere, for the water is four feet deep there; from this point the floor rises in each direction. The roof is not far from the surface of the ground; at a spot near B daylight is visible through it. In other places the roots of bushes hang down from the roof, or have entered the passages through joints in the limestone. The plan of the cave shows clearly enough that the passages are merely widened joints. The width of the passages varies considerably, and at most is about 8 feet. Though the walls, which have an inclination towards the south of west, are in many places coated with a deposit of carbonate of lime, there are few well-developed stalactites; those which were once there have been broken off.

There are said to be other caves or passages in the Kaap Plateau, on the Kono Reserve and Kogel Fontein. The strong springs which issue from the level ground on the Manyeding and Groot Vlak Fontein Reserves, and on Bothetieletsa, may well come from similar fissures in the limestone. Near Geluk there is a well-like hole through shaly limestones, in which water stands at a level of about 17 feet from the surface. The supply was maintained when 270,000 gallons a day[2] were being pumped out.

Springs are more numerous and yield a larger volume of water in the Plateau than in any other part of the area between the escarpment and the Langeberg range. In several places I was assured that these springs do not yield as much as they did a few years ago, and on several farms the springs marked on the Divisional map were not flowing in 1906. With regard to the Kuruman spring, there is no evidence to decide whether the flow is less than in former years. The people in Kuruman say that the flow is constant throughout the year, and from year to year also. There is, however, a dry channel, not long deserted, at a slightly higher level than the present exit of the main spring, and unless the water which once flowed along the higher channel has found a lower exit, the flow must have decreased.

The Kuruman spring issues at a spot which lies at a comparatively low level, and its position is such that it would be possible for the water which falls on a very large part of the Kaap Plateau to find exit there. The geological structure of the country is also such that the limestone strata, so favourable to

[1] I was kindly assisted in making the plan by Mr. J. H. E. Mayne, Magistrate's Clerk at Kuruman.

[2] This figure was taken from an engineer's report shown me by Mr. Abt.

the development of underground channels of considerable width, dip gently towards the Kuruman hills from the east; therefore, if there were any obstacles, such as impervious beds, faults, dykes, or vertical masses of chert, which impede the flow of water westwards under the Kuruman hills, it would issue on the east side of those hills. My survey failed to discover any such impervious body of rock or dislocation likely to intersect the westward flow of the water from the Plateau, and so I cannot assign a reason for the occurrence of the spring at the particular spot where it issues. There can be little doubt, however, that the water at Kuruman and the other smaller springs on the Plateau comes eventually from rainfall on the Plateau. All these waters are very hard; their temperature is above the air temperature on a cold day and below it in hot weather; at Kuruman, the water was at 64° F. at the drift in July and November.

There is no such strong spring as the Kuruman fountain at any other place on the east flank of the Kuruman-Asbestos range, though small springs are not infrequent. Near Daniel's Kuil there are dykes of dolerite traversing the dolomite approximately parallel to the strike of that rock. These dykes (possibly the isolated outcrops belong to one and the same dyke) are probably responsible for the appearance of the fairly strong supply of water at the surface at Daniel's Kuil village. In this part of the Plateau the drainage lines run eastwards, towards the escarpment on the Vaal River valley, and the conditions are therefore less favourable to the occurrence of a large quantity of water than at Kuruman. The springs and wells near Daniel's Kuil were plainly showing in 1906 the effects of deficiency in rainfall during the past ten years.

The hole in the ground from which Daniel's Kuil got its name may originally have been similar in nature to the water-hole (called the Wondergat) at Geluk; but the Daniel's Kuil is dry, and there is no record of its ever having had water in it. Both holes certainly owe their existence to the removal of rock by solution. In the case of Daniel's Kuil, the limestone is no longer visible in the hole, which is now about 15 feet deep, and in process of being filled up with rubbish; the walls are made of a reddish earthy material, and they recede some feet from the opening, which is through a hard ferruginous gravel.

(b) The Maremane Anticline.

This area of the Campbell Rand series occurs along the crest of a broad anticline, which has been traced from the south of Hay in a north-north-easterly direction to the neighbourhood of Klipfontein (north of Postmasburg), and thence in a north-north-westerly direction to Kathu. The dolomitic limestones first appear at the surface between Wolhaars Kop and Sweet

Fontein, on the Postmasburg River, and they are constantly seen as far north as the dry valley which traverses the anticline from the Khosis Reserve to Gamagara. North of this valley the Campbell Rand beds were not seen, but there can be no doubt that they underlie the country between Kathu beacon hill and the north end of the Gamagara ridge, for the calcareous tufa or surface limestone becomes very thick in that area, and the dip of the Griqua Town beds on the Kathu beacon hill is directed away from this tufa-covered ground.

In general appearance this dolomitic limestone area resembles the Kaap Plateau[1]; the character of the vegetation is the same and large parts of the surface are very rough in detail, though, disregarding the hills of Blink Klip breccia, the whole looks flat. The ridges and outliers of Blink Klip breccia are, however, very characteristic of this anticline, whereas a precisely similar rock does not occur in the Kaap.

On the east the Campbell Rand limestones dip at low angles under the Griqua Town beds of the ridge which extends south-eastwards from Kathu beacon to the neighbourhood of Riet Fontein, in Barkly West, and thence south-westwards past Postmasburg. This boundary shows very distinctly the rather extraordinary bend which all the main structural lines take in southern Bechuanaland and the north of Griqualand West.

The southern extremity of the limestone disappears under surface deposits east of Wolhaars Kop, but its approximate position is not difficult to lay down on the map, because there are outcrops of the younger beds in suitable places. From Wolhaars Kop northwards to M. 93, the limestone dips at low angles under the Griqua Town beds, which there form a low ridge. An outlier of the latter beds, or an extension of a band of them lying south of the Vlak Fontein syncline,[2] partly separates the limestone of the western border from that of the main area, but the surface deposits conceal the details of the structure between this patch of Griqua Town beds (on M. 80 and M. 93) and the south end of the Gamagara ridge. The dolomitic limestone crops out west of that ridge, between it and the Ongeluk beds of the Vlak Fontein syncline; but there must be faults here, in addition to the Paling fault, the existence of which is greatly confirmed by the results of last year's work. The position and nature of the subsidiary faults must remain uncertain for the present, owing to the general thick covering of surface deposits and the lack of artificial exposures. From the south end of the farm Paling to the westernmost corner of Sekgame, in the Kuruman district, a distance of about 34 miles, the limestone

[1] The name Kaap Plateau seems now to be confined to the country east of the Kuruman—Asbestos range, but on some of the original diagrams of farms in the Hay portion of the Maremane anticline, *e.g.*, Klipfontein, the farm is said to lie on the Kaap Plateau or range.

[2] See Ann. Rep. Geol. Comm. for 1905, p. 188.

area is bounded by the Blink Klip breccia of the Gamagara ridge. The condition north of Kathu will probably remain unknown for a long time, for the country there is covered with a thick deposit of tufa, and the two dry valleys leading northwards to the Kuruman River through this neighbourhood are not excavated deeply enough to expose their bed rock, or, more probably, they have been filled in with tufa too deeply to allow the rock to appear below Cowley in one case and Gamagara in the other. The Paling fault probably extends some distance north of Sishen. The downthrow is to the east, though at an earlier stage it must have been to the west.

In character the Campbell Rand beds in this area are very like those in the Kaap Plateau, and there is no need for a special description of them. The upper beds are not so well exposed here as on the Gamohaan and Daniel's Kuil hills. As a whole, this area is less well watered than the Kaap; there are considerable springs at Postmasburg, which issue near the outcrop of a dolerite dyke, though this dyke appears to terminate some hundred yards from the springs. Further down the Postmasburg River (dry), there are also strong springs rising from the calcareous tufa, which, to a great extent, hides the underlying rock in that neighbourhood. The wells on the Maremane anticline are not numerous, and there have been several failures amongst the few sunk. The depth to which they have been sunk is not great, not more than about 60 feet. Boring for water has not been attempted, so far as I know. There can be little doubt that water will be got by boring, though, as the area has a smaller catchment than the Kaap, and as the beds are in the form of an anticline, the quantity available is almost certainly less than in the latter district. I have left out of account the possibility of some of the water from the Kaap flowing under the wide syncline of the Kuruman hills, etc., for the level of the surface west of the syncline is only slightly lower than that of the Kaap, and its rocks form an arch which is separated from the possible source of supply, not only by the syncline but also by a large area of the Ongeluk volcanic rocks. The structure under this volcanic area is not known, but it is not improbable that there are dykes or other bodies of igneous rock which may interfere seriously with the movements of water underground.

At the present time the limestone areas have a bad reputation for stock farming, but when the farmer can properly guard against "lamziekte," the great possibilities in the way of underground water supply in these areas will attract people. Boring operations will not be easily carried out, for the difference in

hardness between the dolomitic limestone and the chert, which will almost certainly be met with in the greater number of holes, will make difficulties, as will also the hollow spaces dissolved out of the limestone by the underground water.

Volcanic Rocks in the Campbell Rand Group.

In the 1905 Report, p. 247, Mr. du Toit describes some lavas at the top of the Black Reef beds near Vryburg. Similar lavas were found on New York, lying above the Black Reef beds, and separated from them by several feet of thin dolomites and dark shales. This band of volcanic rocks was not seen on Mooi Fontein or Geluk, nor further west. Its thickness is probably under 100 feet. The rocks are very like the lavas below the Black Reef.

Though they lie on a somewhat higher horizon, judging from the lithological character of the sedimentary rocks, these lavas are almost certainly a continuation of the belt mapped last year.

C. The Griqua Town Series.

The past year's work has made it advisable to extend the meaning of this term so as to include both the Ongeluk volcanic group and certain sedimentary rocks overlying these in the north-west of Hay and the south-west of Bechuanaland.

In the Report for 1905 it was stated that the sedimentary rocks west of the Lucas Dam syncline belong to the upper part of the Griqua Town series, but I was then under the impression, owing to a strong lithological resemblance between the two sets of rocks, that these western beds were merely a repetition of the beds seen east of the supposed syncline, and that there was an overfold here. An examination of the northward continuation of the same belt of country has shown that the views expressed in that Report are wrong, and a re-examination was made of part of the belt seen previously in Hay. This has shown that the view now adopted is very probably correct, and the new view clears up several difficulties that were not met by the old. The error was corrected too late to be made good in the text of the 1905 Report, but a fly-sheet, dated October 15th, 1906, was printed for distribution with the Report, and the error is pointed out therein.

The reasons for thus enlarging the Griqua Town group will be apparent from the facts described below.

The Griqua Town series occupies a wide area in this district. It first occurs in the long line of hills called the Asbestos and Kuruman ranges, the eastern limb of a wide syncline in this group. The western limb gives rise to the lower range stretching from Kathu, past Khosis, to near Postmasburg, where it is

..ent round towards Wolhaars Kop, or concealed by recent deposits for some miles; it or a similar structure can, however, be followed in isolated patches of rock past Matsap into the eastern limb of the anticline between the Juanana and Abram's Dam synclines. West of the line of country indicated, the structure is more varied, owing to the presence of several synclines in the south. The formation disappears under the Matsap beds of the Langeberg group of ranges in such a way that the fullest succession is seen in the north, and the gap represented by the unconformity at the base of the Matsap series becomes steadily greater towards the south.

It will be convenient to describe the rocks and their distribution under three heads:—

3. Upper group, sedimentary rocks.
2. Middle or Ongeluk group, chiefly volcanic rocks.
1. Lower group, sedimentary rocks.

(1.) *Lower Group.*

This group includes all the rocks above the Campbell Rand limestones and below the lowest volcanic rocks of the Ongeluk group. Thus defined, it builds up the Asbestos-Kuruman range, the Kathu-Khosis hills, the hills south of the Matsap area and between the latter and the Langebergen, the Wolhaars Kop ridge, and the peculiar breccia hills of the Maremane anticline.

The rocks of this group were described in the last Annual Report,[1] so there is no need to repeat the description here, but a few fresh specimens of the more abundant types of rocks have been examined under the microscope, and more examples of the glacial beds have been similarly dealt with.

A banded black, brown, and white magnetic rock from Jacob's Fontein, in Hay (1589), is seen under the microscope to contain a large amount of colourless or slightly yellow-stained cherty material, made of very small quartz individuals, which overlap each other and are intricately interlocked. Through this run lines along which iron ores are concentrated. These lines are the lamination planes of the rock seen in section. The iron is in two forms, magnetite and an opaque brown ore. The magnetite is mostly in thin layers and irregularly-shaped clusters of grains, but it also occurs in certain rhomboidal areas which are seen in the section. These areas range up to one-fiftieth of an inch in length, and are scattered sparsely through the chert matrix, being often only distinguishable by a narrow limiting line of brown oxide of iron; the material within this limit is often chert, just like the chert outside, but there are sometimes irregular patches of brown iron ore with or without minute grains

[1] Ann. Rep. Geol. Comm. for 1905, pp. 156–164

of magnetite in them. Along the lamination planes those rhomboidal sections are much more abundant than elsewhere, and in these planes they are generally filled in, chiefly with brown oxide, together with some magnetite. In a few cases the magnetite almost fills the area to the exclusion of both the brown oxide and the chert. The rhomboidal sections represent former crystals of carbonates, and the hydrated and magnetic oxides of iron in these sections are secondary products. It is likely that carbonate of iron (siderite) was once a constituent of the rock, and that at least part of the iron ores now forming a considerable portion of the rock are due to an alteration of the iron compounds originally in the deposited sediments. A difficult question to settle is whether all the brown oxide now present is a direct result of changes in the carbonate of iron supposed to have existed formerly, or whether some or all of it is due to the oxidation and hydration of the magnetite.

A fine-grained sandstone, brownish and grey in colour, from a depth of about 40 feet in a well on Westfield, shows in thin section (1601) a collection of quartz grains, evidently of detrital origin, cemented together by a matrix of a pale greenish-blue chloritic mineral and perhaps chert. There are also numerous small patches of a carbonate with brown oxide of iron. There is nothing referable to crocidolite in this section.

A section (1595) through a heavy banded blue, green, and brown rock from Kort Kloof Fontein is seen under the microscope to have a base of chert crowded with needles and matted tufts of two minerals, one of which is yellow and shows fairly high colours between crossed nicols, and the other is pale greenish-blue with low double refraction. The needle-like crystals are mostly of the blue mineral, and the denser parts of the aggregates are formed chiefly of the yellow, but the two minerals are certainly closely related, probably one of them is an alteration product of the other, and it is more likely that the blue is the earlier. This greenish-blue mineral resembles that called chloritic in the previous paragraph, and is not the same as the pleochroic crocidolite seen in some of the Griqua Town rocks of Prieska[1] and Hay.

A section (1492) has been made of one of the very tough, heavy blue rocks, fragments of which are frequently picked up on the surface in Prieska and Griqualand West. It consists almost entirely of densely-matted fibres of crocidolite, but there are scattered through the crocidolite small paler areas, in which there appears to be some chert.

The Glacial Beds.

During the past year these beds have been examined at places where they have undergone much less change than at the locali-

[1] Ann. Rep. Geol. Comm. for 1905, p. 157.

ties described in the 1905 Report. The specimens described below from thin sections come from the south-eastern side of the large syncline of Ongeluk beds in the middle of Hay, and from the outliers on Good Hope, in Barkly West. The chief difference which separates these rocks from the glacial beds in some other localities is that they are dark blue-grey in colour, and the fragments of limestone in them are preserved. The prevailing red and brown colours of the glacial beds over a great part of their extent were remarked upon in the 1905 Report, and it was also stated that certain cavities partly filled with iron ores possibly represent original limestone pebbles. Limestone pebbles are abundant in the blue rock from the localities mentioned above; the limestone is a finely crystalline white marble, occasionally it is banded owing to the alternation of thin grey and white laminae.

A section (1593) through the blue rock from Kort Kloof Fontein in Hay shows that a large part of the matrix is carbonate of lime or magnesia in small irregular crystalline grains; a rough estimate of the amount of carbonate present in the section gives its proportion as one-third of the whole. With the carbonate there is a colourless very fine-grained chert; in this matrix lie small angular and rounded grains of clear quartz, minute ragged flakes of a slightly pleochroic pale-brown mineral which seems to be bleached biotite, a very few grains which may be felspar, crystals of magnetite, and a grain or two of a highly refracting and polarizing mineral, such as zircon, which, however, was not determined with certainty. Chert and marble form larger fragments. In some cases the pieces of chert are sharply bounded, and appear to have been much in their present condition since the rock was deposited, but in most cases the chert pebbles are so impregnated with carbonates that they almost lose their distinction from the matrix, and give rise to the impression that they represent a stage in the change of limestone pebbles into chert. One of the limestone pebbles has circular areas in it partly converted into chert along concentric layers; these are probably oolitic grains. There are also oval areas of chert in this pebble; there is nothing that can be assigned without much doubt to radiolarian or other organic remains.

Sections (1581, 1582) from the glacial rock on Good Hope, in the Barkly West Division, show a fine-grained matrix, consisting of very small grains of carbonates of lime and magnesia, very small quartz grains, and much indeterminable dusty matter; no chert is discernible. Small sections of octahedral crystals of magnetite are fairly abundant. In this matrix are set larger grains of quartz, angular or rounded, and similarly shaped grains of felspar (orthoclase and microperthite, not microcline or striped plagioclase) which are not abundant, chert, marble, and a few flakes of biotite—fresh, not altered as in the Kort Kloof rock. The chert grains and small pebbles are very sharply defined,

and are made up either entirely of chert or have some carbonates and magnetite in them. There is one rounded pebble of pyrites. One grain of a grit rock is to be seen, but no fragment of an igneous rock, other than the felspar, mica, and quartz grains, is visible.

These three slices are probably typical of a large body of the glacial beds. The rock breaks with a splintery fracture. On Good Hope it has been used for building a house, and though the stone was quarried within the last six years, it is already flaking off on exposed surfaces, and in places it is breaking down into a sandy material.

The difference in position and circumstances between the places where the blue rock, covered only by a thin crust of yellow-brown weathered material, occurs, and those where the red and brown rock described in the 1905 Report are found, will not account for the changes which have taken place in the latter rock. The absence of quarries and wells from the red rock, also, prevents a knowledge of any changes which may be found at shallow depths from the surface. From the generally-observed fact that where the red rock is, the other beds of the Griqua Town series are also highly haematitic, and that corresponding beds in the blue rock areas are not so haematitic, it is obvious that similar changes affect large bodies of rock, and there is as yet no explanation of the circumstances governing the change.

The Blink Klip Breccia.

Though this rock in its typical form appears to be confined to the Maremane anticlinal area, it has been pointed out that the minor disturbances of the basal beds of the Griqua Town series are closely related to the processes that gave rise to the breccia itself.[1] So the account of the work done last year on the breccias will be commenced by a description of the disturbed beds at the base of the Griqua Town series, along the Kuruman-Asbestos range.

On the east side of the Blockhouse Hill, just north of Daniel's Kuil, there is a good section showing, in the lower half of the slope, the dolomitic limestone of the Campbell Rand series inclined at a low angle westwards; then comes a layer of thinly-banded jasper, which is highly disturbed, and this is followed by about 10 feet of limestone, which is also folded in conformity with the underlying jasper. Above this limestone lie thin-bedded jaspers, disturbed below, but gradually becoming flatter and flatter above. About half a mile north of the blockhouse, where the hill is higher, and consequently is capped by a greater

[1] Trans. Geol. Soc. S.A. Vol. IX, 1906.
Ann. Rep. Geol. Com. for 1905, p. 166, 178-9.

thickness of Griqua Town beds than further south, the thinly-banded jaspers are very little disturbed. In another section, a few hundred yards north of the one described above, the main body of jaspers descends obliquely across the upper 10-foot limestone the thin jasper band and part of the lower and main group of limestones. These descending beds are folded into a sharp synclinal form, and there is broken rock visible below them in a few spots where exposures occur in suitable positions; the broken rock probably represents the thin bed of jasper. The total displacement of the upper jaspers reaches a maximum of quite 30 feet.

Similar sections are visible below the hill on which the Gamohaan beacon stands, north-west of Kuruman.

There are probably many places between Kuruman and Griqua Town where sections more or less similar to those at Daniel's Kuil can be seen, but for long stretches the junction is concealed by soil, angular debris, and ironstone gravel.

On the farm called Mount Carmel, and on A. 112 and A. 113, there are seven outliers of the Griqua Town beds lying at various distances up to 1½ miles eastwards from the main body of the series. One of these outliers was identified without difficulty with the hill called Ramaje's Kop by Stow,[1] and through which he drew a section. I could not find any spot where the

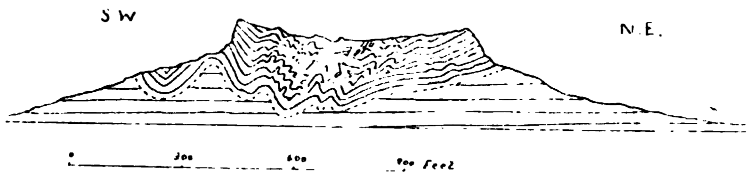


FIG. 3.—Section through the outlier of Griqua Town beds in Ramaje's Kop on Mount Carmel, Barkly West. The bottom undisturbed beds are the Campbell Rand limestones and the upper, crumpled and broken, rock the Griqua Town series.

contact between the jaspers and the limestone was visible, but otherwise Stow's description and section give a good idea of what is now to be seen. The breccia bands, however, are not so definite as Stow's drawing would lead one to expect. A generalised section through this hill is represented on Fig. 3. The details are too intricate to be inserted, but the main points are the existence of the folds on the western side of the hill and of the highly broken zone in the middle, followed by much less disturbed beds on the north-east side; the Campbell Rand limestone is well exposed round the lower half of the hill, and shows no deviation from the steady westerly dip. The trend of the largest fold in the jaspers is about W.N.W., but in the central part of the outlier there is no recognisable order in the positions

[1] Q. J. G. S. Vol. XXX, p. 665.

of the various blocks and fragments of these rocks. In this place the Griqua Town beds seem to have collapsed into a cavity, of which the W.N.W. axis was rather longer than any other; the cavity must have been deep enough to bring about the fracture of the jaspers in the part where they had to move furthest, *i.e.*, the middle of the hole.

On the beacon hill at the south end of Mount Carmel there are intensely folded beds. The axial planes of these folds may lie in any direction, some of them are nearly horizontal. The length of a limb between trough and arch may be as much as 5 feet. The junction of these contorted Griqua Town beds with the limestone is not seen, but, as usual, the latter rock lies undisturbed in the lower slopes of the hill. The folded rock is very well exposed here, and the sharply curved surfaces of many beds can be examined closely. They show no slickensides, such as are seen, *e.g.*, on the surfaces of the folded Witteberg beds north of the Zwartebergen. They give one the impression that the folding took place when the jaspers were in a plastic condition, so that layers moving at different rates did not scratch one another. These facts appear contradictory of the evidence afforded by the brecciated parts of the rock, for the latter is made up of quite sharp-angled fragments of the banded jaspers. The phenomena in these hills, in fact, seem to show that the process of adjustment of the Griqua Town beds to the hollows dissolved out of the limestone is to be divided into two parts: (1) an earlier adjustment when the beds dropped down by their own weight and at a time when they were plastic, and (2) a later filling in of the enlarged holes by the falling down of the fractured hard beds.

Though the outliers north of Daniels Kuil contain rock which is indistinguishable from some of the Blink Klip breccia, the latter only occurs in its typical forms in the Maremane anticline.

In the 1905 Report[1] a description was given of those masses of the rock within the Hay Division, but a further examination has been made of two important localities in Hay, the kopje near Postmasburg and Wolhaars Kop, which could only be cursorily looked at in the former year.

The breccia which forms the hill near Postmasburg (the Blink Klip Kop or Sensavan) makes an oval outcrop about 500 yards long in a N.N.E. direction and 300 yards wide. On all sides the Campbell Rand limestone appears at the surface, and the actual contact of the two rocks is to be seen at several spots round the northern end of the hill. On the north-eastern slope there is a large cavern, from which the natives have dug out red haematite from an unknown date. The walls of the cave are made of breccia containing a very large proportion of haematite, and between masses of the usual hard rock there are bodies

[1] Ann. Rep. Geol. Com. for 1905, pp. 174-179. Figs. 3 and 4 in that Report (pp. 172 and 176) were unfortunately transposed.

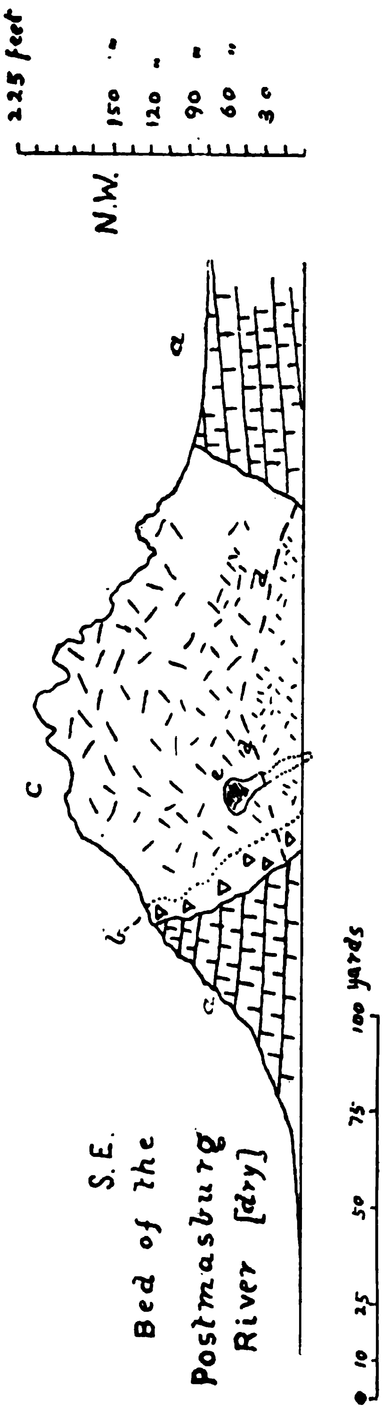


FIG. 4.—Section through the Blink Klip Kop. *a.* Campbell Rand limestone. *b.* brecciated limestone. *c.* Blink Klip breccia. *d.* dotted line showing position of limestone breccia on N.E. side of hill. *e.* excavation made by natives.

of softer haematite, quite irregular in shape. This soft haematite can be crushed between the fingers, and was evidently the chief object of the natives' search, for the cave has been enlarged in all directions along streaks and pockets of this substance. There are variously shaped patches and strings of calcite in the breccia, otherwise no other material than the haematite breccia is to be seen in the walls of the cave. From the cave a narrow passage leads downwards in a southerly direction, which I followed for about 40 feet; the floor is soft haematite, and the walls and roof are a very irregularly-shaped surface of the hard rock. A farmer near by told me that he once went 50 yards down the passage, but that it has become blocked by fallen rock. This extension of the cave may perhaps be in part an original feature, though its present size is certainly due to excavation by the natives. The Campbell Rand limestone crops out on the eastern side of the hill at a height of about 80

feet above the lowest part of the cave accessible at the time of my visit, and on the western side it is seen to be about 40 feet above the same level; directly north of the hill it crops out a few feet above the level of the cave floor within a distance of 50 yards. Fig. 4 shows a section through the hill drawn roughly to scale. Between the limestone on the east and the typical breccia there is a belt of brecciated limestone containing a small amount of haematite; this belt is nearly 10 feet wide, and extends round the north end of the hill. There are spots on the eastern flank of the hill, where a limestone breccia probably does not exist, for the normal limestone and the haematite breccia approach each other very closely.

In this hill, therefore, we have a proof that the Blink Klip breccia here fills a fissure or elongated hole in the Campbell Rand limestone, which is practically undisturbed a few feet from the breccia, and in places unbroken up to its contact with the latter. At no other locality has such complete evidence of the position of the breccia been obtained, though the partial section given on p. 172 of the 1905 Report indicated such a position.

The lower part of this hill consists of richly haematitic breccia in which the irregular fragments of banded jasper are less numerous than usual; the matrix is increased in quantity. Small crystals of iron pyrites were seen occasionally in the red haematite. On the southern slope of the hill there is a second excavation, now almost filled by the falling down of the roof or walls, and the rock exposed there is similar to that in the large cave. The top of the hill is made of the hard breccia described in the 1905 Report.

Wolhaars Kop is a prominent summit of a ridge 10 miles south-west of Postmasburg. It lies on the western side of the anticline, where the beds begin to have a decided westerly dip. The Campbell Rand limestone forms the low ground east of the kop, and the western slope is cut out of the usual banded jaspers of the Griqua Town series; then follow the Ongeluk volcanic rocks and the uppermost division of the Griqua Town series. Thus the whole succession from the Campbell Rand beds to the unconformity which truncates the Griqua Town series in Hay is seen in this neighbourhood. The breccia of the Kop lies between the limestones and the westward dipping banded jaspers. In last year's Report it was stated that the breccia is over 200 feet thick; but the maximum thickness must be nearly 400 feet, though it is difficult to draw a line to indicate the upper limit. Near the eastern base of the hill and for some 200 feet up the slope highly haematitic rocks containing angular fragments of banded jaspers and chert are seen. In the upper part of the hill occur banded rocks, very much broken up, and cemented together again by haematite and iron-stained silica; these rocks are great shattered masses, just like those described last year from the Klip Fontein ridge. The general trend of

the shattered rock is about N. 10° E., roughly parallel to the western limit of the anticline in this neighbourhood. These broken-up banded rocks give place to less broken beds as one descends the western slope of the hill, *i.e.*, as one traverses higher and higher beds in the stratigraphical succession, and finally unbroken beds are met with. The banded cherts of the western slope are in places repeatedly faulted on a small scale; the throw of any one fault may be only an inch or less, or it may be several inches. Both normal and thrust faults are seen. A thick band of reddish quartzites interbedded with the cherts seems to have checked the fracturing of the rocks, for above it the beds are not broken.

The Klip Fontein ridge extends into the Kuruman Division, and is in all about 22 miles long. The Thaakwaneng Trigonometrical beacon (5,180 feet) stands on it. There is not much to add to the description of this ridge in the 1905 Report. On the east side of the ridge near Thaakwaneng the Campbell Rand limestone rises high above the base of the breccia. Northwards from this ridge there are several outliers of the breccia situated on the Maremane and Khosis or Gathlose Reserves. Through not quite aligned on the extension of the Klip Fontein ridge, seven of these outliers are nearly in that position. These hills are made of ferruginous and siliceous breccias very like those of the Klip Fontein ridge. Eight more of these outliers were found in the Maremane Reserve and to the south of it. The Bechuanaland rinderpest fence crosses two of these; the larger one is the Mount Huxley of the maps. Mount Huxley is a mass of breccia with its longer axis lying N.N.W. The limestone crops out at higher levels than the lowest visible breccia at both the north and south ends of the hill. The breccia is rather less ferruginous and more siliceous than the average rock of the Klip Fontein ridge.

The curiously abrupt crag called Kopje Aleyn lies about two miles N.N.E. from Mount Huxley. It is a mass of breccia with a rough vertical jointing, rising very steeply from the grassy flats on the farm Gopthorne.

The Gamagara ridge is the longest mass of the Blink Klip breccias; it is the extension of the Paling ridge in Hay, but as the well-known name of Gamagara is applied to the Trigonometrical beacon (4,105) standing on it, that name can be used for the whole ridge. The ridge stretches from Paling to Sekgame, a distance of some 31 miles, though it is probably discontinuous on Lomoteng, where the Campbell Rand limestones seem to be in direct contact with the Matsap beds for some few hundred yards. The material in this ridge is very like that in the Klip Fontein mass; much of it contains a large proportion of haematite. The rocks have not yet been analysed, and there is no need to repeat the description of the various kinds of breccia, which differ from each other in the amounts of iron ores and

silica, and in the degree of comminution of the banded fragments. There are two special points of interest in this ridge. Firstly, the occurrence of crater-like hollows on Bruce; and secondly, the fact that the breccia is directly overlain by the Matsap beds. The southern crater-like hollow on Bruce is about 50 yards wide, filled in with red sand and surmounted by a rather steep wall, 10–15 feet high, of more or less broken, highly-ferruginous banded rocks; great slabs of this rock dip sharply towards the hollow on the south-east side. On the north-west side there is a break in the wall, caused by running water. The hollow at once reminded me of the Balmoral (Fraserburg) volcanic pipe, but there is no evidence, such as the occurrence of unusual minerals in the floor of the hollow, that the latter had the same origin as the Balmoral pipe. It seems likely that the hollow is situated on a circular sink-hole in the limestone, but there is no means of settling the question at present. The northern hollow on Bruce is similar to the one just described, but it is wider (about 120 yards wide), and its walls are lower.

The lowest part of the Matsap beds are very ferruginous when they lie on the breccia, and well-rolled fragments of the latter rock were found in the Matsap beds. In places the Matsap beds are so largely made up of debris of the breccia that the distinction between the two rocks is not easily drawn. The occurrence of layers of fragments and the bedding of the Matsap beds with constant westerly dip, however, separate them from the breccia. These rocks will be mentioned again on a later page.

In the Gamagara ridge there are slickensided surfaces in the breccia; their appearance is sufficient to show that they were subsequent in date to the formation of the breccia. Probably they represent small faults, produced at the same time as the long fault which forms the western boundary of the Gamagara ridge (see Fig. 5).

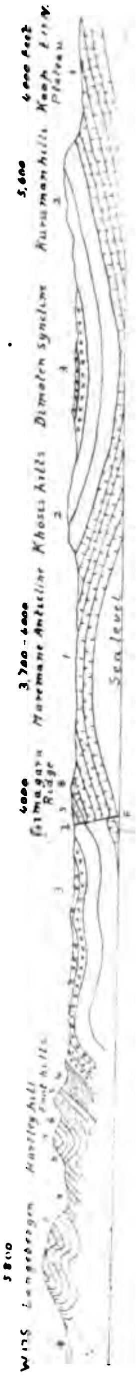


FIG. 5.—Section from the Kaap Plateau to the Langebergen, distance 66 miles; vertical to horizontal scales, 3 to 1. 1. Campbell Rand series. 2. Lower Griqua Town beds. 3. Middle Griqua Town beds, or Ongeluk beds. 4. Upper Griqua Town beds. 5. Lower Matsap beds. 6. Middle Matsap beds. 7. Upper Matsap beds. 8. Surface sand, etc. B. Blink Klip breccia. F. Paling Fault.

From the occurrence of boulders and smaller debris of the breccia in the Matsap beds, the age of the breccia is determined, at least as regards its later limit; and it is clear that a great part if not all of the haematite had also been accumulated when the Matsap beds were deposited.

The Distribution of the Lower Griqua Town Beds.

The chief area where these beds crop out at the surface is that of the Kuruman-Asbestos range, which trends S.30°.E. from the Kuruman River[1] past Kuruman to the Barkly West boundary; then it turns southwards past Daniel's Kuil to the Hay boundary, and trends S.S.W. past Griqua Town to the Orange River. The great bend in the strike about the line running E.N.E. from Andries Fontein has been referred to before, and is very clearly seen in the case of this boundary. The beds in this area dip westwards under the Middle or Ongeluk group in Hay and Kuruman, but these volcanic rocks in the syncline have been entirely removed by denudation over a wide area west of Daniel's Kuil, and probably also between the Dimoten volcanic area and that of Langar, etc., west of Kuruman. The Lower Griqua Town beds reappear in the western limb of the syncline as the Kathu-Khosis hills, the Groen Water hills, and the low hills near Matsap (see Fig. 5). They then form the eastern limb of an anticline, which is wide in the north (Maremane anticline), but which contracts southwards, and can be recognised in the rather narrow anticline between the Juanana and Abrams Dam synclines described in the 1905 Report. The westernmost occurrences of these beds seen during 1906 are near the Matsap outliers in the Koegas Field-Cornetcy, in the narrow strip on the west of the Paling fault, and in the Wolhaars Kop hills.

The observed range of the glacial beds has been extended as far north as the country north of the Kuruman-Kathu road, on the farms Ettrick and Cropwell, where good specimens of striated stones were found lying in a fine-grained matrix. West of the Paling fault, the glacial beds were traced up to Bishop, and they are well exposed on Lomoteng. They are seen round the Dimoten syncline of Ongeluk beds, and the two outliers of the latter called Monjana Mabedi. These are prominent hills on the north-east side of Khosis Reserve; a corner beacon of that Reserve stands on one of the hills. The upper 200 feet or so of each hill consists of lavas, and the lower 150 feet of the Lower Griqua Town beds. The glacial beds are not very well exposed, but in a few gullies they are seen, and in these situations, especially near a dried-up spring on the south-eastern hill, the rock is decomposed into a muddy material, from which the

[1] For the northward continuation of this range see the paper by G. G. Holmes in Trans. Geol. Soc. S.A. vol. VII. p. 130 and plate.

enclosed stones can be picked out. Where outcrops occur on other parts of the hillside, the rock is the hard blue variety, like that of Good Hope, with a thin weathered crust. At Monjana Mabedi there are some 12 feet of thin-bedded dark quartzitic rock lying between the highest outcrops of the glacial beds and the lowest Ongeluk lavas. Although the boulder beds are here calcareous and contain much limestone, in the shape of fragments of marble, the dark rock overlying them is not calcareous.

On the south-eastern part of the Ongeluk-Witwater syncline there are good sections exposed on the hillsides, showing a succession like that given in Fig. 6 of the beacon hill of Punt, Dunmore, and Schanz. The occurrence of the 40 feet of quartzite with pebbles (No. 4 in Fig.) is rather peculiar, for beds with

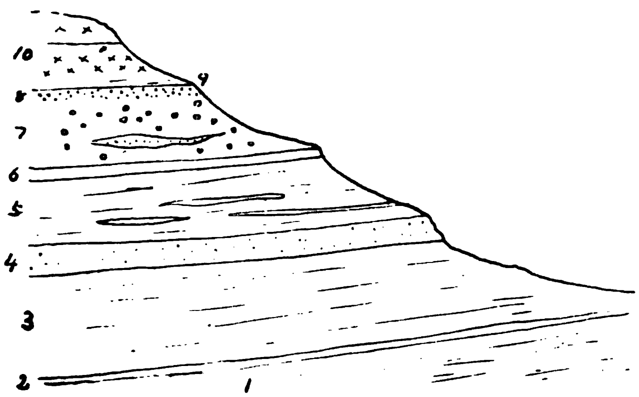


FIG. 6. Section on the hill where the beacon common to Punt, Dunmore and Schanz stands. 1. Brown magnetic jaspers. 2. Flaggy blue fine grained rocks. 3. Thin bedded ferruginous rocks; 100 feet. 4. Coarse quartzitic sandstone with pebble beds; 40 feet. 5. Thin bedded ferruginous rocks with lenticles of limestone. 6. Hard black jaspery rock. 7. Blue quartzitic mudstone with striated boulders, a patch of gravel in the mudstone. 8. Gravelly conglomerate; 8 feet. 9. Blue thin flaggy beds; 12 feet. 10. Ongeluk lavas.

similar characters are not often seen on this horizon, though their hardness would cause them to make good outcrops. The quartzite contains grains of felspar and pebbles of cherty ferruginous rock; some of them are now represented by lumps of ochre. On Koodoo's Kop a very felspathic sandstone occurs on about the same horizon, *i.e.*, some 200 feet below the lowest lavas, and is 30-40 feet thick. A grey quartzite in a similar position was noticed east of Matsap. In the Kuruman district no rock of this kind was seen in the Lower Griqua Town beds, though the exposures between Khosis and Monjana Mabedi are so complete that any rock of this nature would have been seen if present; near Monjana Mabedi there are grits just below the

glacial beds, as there are in several places in Hay, but these grits have nothing to do with the thick sandstones and quartzites at the lower horizon in Hay.

(2) *The Middle Griqua Town Beds.*

The Ongeluk volcanic beds form the greater part of this sub-group. The stratified sedimentary rocks other than volcanic debris associated with the lavas consist of banded jaspers. These rocks were partly described in the last Annual Report, p. 182, but other varieties have been found, and thin sections cut from a few of them. They are all brittle rocks, and all more or less banded, owing to the greater abundance of iron oxides or other colouring matter in some layers. It is rarely that they are well exposed *in situ*; they are usually seen as fragments along certain lines, the latter probably mark the positions of the strata under the soil. On Hartfell (Koegas F.C., Hay) there is an outcrop of bright red jasper between thick masses of lava in the Abrams Dam syncline. A section (1604) has been cut from this rock perpendicularly to the banding; it is seen under the microscope to be made up of small quartz areas, like chert, with red colouring matter through it. The colouring matter is in the form of extremely minute dots, without definite shape so far as one can see with a one-eighth inch objective; the small circular areas in which these dots are crowded have a reddish appearance in transmitted light. These crowded areas measure ·07 mm. or less in diameter, and in at least a great number of cases each crowded area lies within one individual grain of quartz (or other form of silica). Certain bands of the rock are fairly free from clusters of dots, and the quartz areas in them are somewhat larger than in the red part; these are the white layers of the hand-specimen. The banding is occasionally interrupted by the appearance of roughly circular or oval clear patches, rather irregular in outlines, and made of rather larger quartz areas than the bulk of the rock. Magnetite occurs in small octahedra. There are several flakes of a peculiar green mica, a mineral similar to the mica in one of the banded magnetic rocks of Doornberg[1] (on the farm Nauga). The absorption scheme is that of ordinary biotite, except that shades of green take the place of the red-brown colours of biotite. A few small colourless garnets are cut through by the slice. In some hand-specimens of this jasper from other localities the garnets are one-tenth inch in diameter, and have pale yellow and brown colours. On Taaibosch Puts a banded black, green, and grey cherty rock occurs. The black portions are very magnetic. Under the microscope, the ground mass is chert, or quartz in much larger individuals than in chert. The black part is due to the occurrence of vast numbers of very minute grains of magnetite,

[1] Ann. Rep. Geol. Com. for 1905, p. 157.

apparently without crystal forms. The green bands are chiefly epidote in rather large yellow pleochroic plates. The grey bands are mostly chert or quartz, and what seems to be garnet. The mineral taken to be garnet is in spherical aggregates without crystal faces; it is nearly colourless, and has a higher index of refraction than epidote, and it is isotropic. In most parts of the slice these aggregates are to be seen; often they coalesce over considerable areas to form irregular layers. The smaller aggregates are of such a size that they lie within the thickness of the slice (·02—·03 mm.), and the layer of chert outside them is still thick enough to give light-grey tints between crossed Nicols, so that these small lumps do not appear to be isotropic. That they are really so is shown by their behaviour under contiguous but differently orientated quartz individuals, when each portion extinguishes with the remainder of each quartz area.

The explanation of the peculiar constitution of these coloured cherts or jaspers has not been found. Their mode of occurrence points to their having been sediments laid down between successive flows of lava, and their mineral constitution shows that they have been greatly altered from their original mineral composition, though the alteration seems to be too great and uniform to be attributed to the influence of the overlying lava.

Outcrops of the lavas of this group have been met with as far north as the latitude of Gamopedi, but the rocks certainly extend further north through country which has not yet been examined. In the last Annual Report descriptions were given of seven synclinal basins of this group, but one of these, the so-called Lucas Dam syncline, has been found not to be a syncline; the supposed overturned western limb has been examined again, and followed northwards nearly to the north end of the Langebergen, where it becomes hidden by superficial deposits. Throughout its known length, about 55 miles, the Ongeluk volcanic rocks dip under the Upper Griqua Town beds In the Kuruman district the Vlak Fontein syncline disappears; the Ongeluk lavas of Vlak Fontein become continuous with those stretching northwards from Lucas Dam, and together they form a wide stretch of undulating ground south of the Gamagara valley. This piece of ground is but thinly covered with superficial deposits, and is comparatively well populated by Europeans, as the veld is healthy for stock and water is got at moderate depths. The volcanic rocks are certainly continued far to the north of Gamagara, but they are buried under limestone. It seems likely that they are continuous round the north of the Kathu Forest with the Ongeluk beds lying west of the Kuruman hills. These latter beds were seen for the last time cropping out below surface limestone down the dry valley which traverses Cowley and joins the Gamagara valley near Honig Draai. There is no sign of the reappearance of the Lower Griqua Town beds of the Kathu hill to the north. The Ongeluk beds west

of the Kuruman hills in the neighbourhood of the Kathu road have probably been separated from the Dimoten syncline by denudation, though the lavas have only been completely removed over two or three miles of sandy ground on Clumber.

The Dimoten syncline is similarly separated from the Good Hope (Barkly West) outliers, and these again from the large Ongeluk-Witwater syncline. During the past year the mapping of the latter syncline was completed, and that of the Abrams Dam and Leelyks Dam syclines was continued, but the latter are much obscured by sand.

So far as the general nature and relations of the Ongeluk volcanic rock to the lower beds are concerned, there is nothing to add to the account given on pp. 180-184 of the 1905 Report, though the past year's work has confirmed the opinion that these rocks follow conformably the banded magnetic and glacial deposits of the (Lower) Griqua Town beds, and has shown that the character of the lavas is constant as far as they have been followed—over an area which extend 130 miles from north to south and 40 from east to west.

Some further thin slices have been cut from these rocks. A lava from one of the Good Hope outliers (1583) is seen under the microscope to have a considerable amount of brownish nearly isotropic base, which looks dusty under a high power, owing to the presence of great numbers of opaque granules; part of the base, which certainly used to be glass, contains small clear spherulitic aggregates of a weakly refracting and polarizing mineral, and grains of calcite. The well-developed minerals are:—(1) Pseudomorphs of bastite after enstatite in small porphyritic crystals; (2) augite in grains and small irregularly-developed crystals; and (3) felspar in very small lath-shaped sections. The structure is that known as hyalopilitic. Another slice from a Good Hope outcrop (1584) shows a similar rock, in which the constituents reach larger dimensions. There is much glass; a rather basic plagioclase appears as thin laths and skeleton crystals. Augite is very abundant in long ill-developed twinned crystals, sometimes enclosing felspar; bastite pseudomorphs are also seen. Amygdales of chalcedony are present. A very similar rock was got from Kort Kloof Fontein (1594). Two sections (1585, 1586) were cut from a rock which closely resembles the Ongeluk lavas in the field, but which was mapped as an intrusion lying south-west of the Good Hope outliers and at a lower horizon in the Griqua Town series. Its appearance under the microscope confirms the field-evidence. It is a holocrystalline rock, consisting of much-alterеd felspar, augite, enstatite, iron ores, and a small quantity of fresh brown hornblende, biotite and quartz. The felspars are almost entirely represented by aggregates of small brightly-polarizing flakes, and are often enclosed by ophitic plates of augite, which also encloses the enstatite. Part of the enstatite is changed to bastite, but much

is still fresh, especially in (1580). The brown hornblende occurs in continuity with some of the augite. There can be little doubt that this mass of rock is an intrusion from the same magma that supplied the extrusive volcanic rocks of the Ongeluk series. A similar rock, which has not however been examined microscopically, forms a large intrusion in the Groen Water area.

An amygdaloidal rock from M. 35 Hay has a glassy base (1592), which is crowded with feathery crystallites like those mentioned on p. 184 of the 1905 Report, and taken to be an amphibole. In this section, however, and in (1596) from Punt, the extinction angles are too large for amphibole, and the mineral is probably a monoclinic pyroxene. The felspar crystals are altered to aggregates of brightly-polarizing flakes; they are sometimes porphyritically developed. Augite also occurs in irregular patches enclosing the pseudomorphs after felspar. Enstatite is represented by bastite pseudomorphs. Amygdales of chalcedony are abundant.

A rock from Langar, in the Kuruman district (1617), shows a once glassy base, now changed to a mass of feathery crystallites, together with small patches of finely crystalline quartz or chalcedony. Pseudomorphs after small porphyritic felspars and skeleton forms of felspar lie in the ground mass. Augite and enstatite were not determined.

A lava from Goup, Hay (1599), is a fine-grained rock made chiefly of minute felspars and augites without porphyritic crystals. The indeterminable base includes some chalcedonic silica.

A rock from a well on Hartfeli, Hay (1603), is rather similar to (1599), but has more ground mass, which seems in part to be glass; it also has a few porphyritic felspars and bastite pseudomorphs. The small felspars are not often twinned, but some larger twinned crystals give symmetrical extinction angles up to 19°, which indicates labradorite. The low extinction angles on the untwinned microlites measured (under 6°), indicate the presence of a more acid plagioclase. From a second well on Hartfell a nearly holocrystalline rock was obtained (1602); the ground mass is of felspar with some chalcedonic silica. Ragged plates of augite enclose felspars, chiefly represented by pseudomorphs. Bastite does not occur in well-shaped pseudomorphs, but in patches enclosed by augite. This rock is more like the Good Hope intrusion than a lava, but its field relations cannot be made out.

All these igneous rocks have a strong family resemblance, and are like those described last year from the Juanana syncline (1905 Report, p. 184, etc.). They are different both in texture and composition from the Ventersdorp lavas, and from those in the Middle Matsap beds. At the present time a thorough comparison with the igneous rocks, apparently intrusive, in

the Pretoria series of the Transvaal cannot be made, but it should be noted that the rhombic pyroxene which is certainly characteristic of the Ongeluk igneous rocks may point to a relationship with the norites of the Transvaal, though the rhombic pyroxene in the latter[1] is chiefly at least hypersthene, a pleochroic mineral probably containing more iron than the enstatite of Hay and Bechuanaland. Lately a volcanic tuff has been found in the Pretoria beds,[2] though no lavas have been described from them. Rocks like the elaeolite-syenites of the Transvaal have not been found in Cape Colony.

The maximum thickness of the Ongeluk or Middle Griqua Town beds has not been estimated with any approach to accuracy. It is probably considerably over 1,000 feet in the Lucas Dam area.

(3) *The Upper Griqua Town Beds.*

These beds have only been found on the west side of the area formed by the Ongeluk volcanic series between Floradale (Hay) and Alister, in Kuruman. The narrow strip of country which they occupy is largely covered with sand, but the lower beds in this group are hard, and appear in long low sharp ridges between the Ongeluk volcanic rocks and the Lower Matsap group. The southernmost part of the strip was described in the 1905 Report (pp. 171, etc.), and the conclusion arrived at was that the beds belong to what is now called the Lower Griqua Town group. The reason for that conclusion was that the brown magnetic jaspers with thin limestones are very like similar beds below the glacial boulder beds, and though the latter rocks were not found *in situ* west of Lucas Dam, etc., pieces of a cherty boulder rock were found, together with a few loose pebbles, which have striations on their surface. On this evidence the beds in question were regarded as being on the overturned western limb of a syncline. There were difficulties involved in this view, especially in connection with the change in character of a great part of the supposed Lower Griqua Town beds and their relation to the quartzites and conglomerates to the west, which were then not understood so well as they now are after further work.

Last year's work showed that the conditions observed on Floradale and Lucas Dam hold good as far north as the beds were seen, *i.e.*, that along the 55 miles of boundary yet examined the jaspers and slates dip at fairly high angles westwards and away from the Ongeluk lavas, and that they are followed by the Lower Matsap group. The dip of the Ongeluk beds is usually difficult to determine, and especially so in an area, such

[1] See Rep. Geol. Surv. Transvaal for 1904 and 1905, especially 1905, p. 72-76, also J. A. L. Henderson, "On certain Transvaal Norites etc.," London, 1898

[2] A. L. Hall, Rep. Geol. Surv. of Transvaal for 1905, p. 53.

as that along the western side of Lucas Dam, etc., where they do not make bold outcrops. Were this an overturned limb of a syncline, one would not expect to find such regularity of dip along such a considerable distance; somewhere the beds would probably be found to dip normally under the Ongeluks. Then again, the many further outcrops examined bring out differences from rather than resemblances to the Lower Griqua Town beds. No outcrops of a glacial conglomerate have been met with, though that part of the group nearest the Ongeluk lavas is fairly well exposed on Mamaghodi and Cox. Throughout the known range of these beds they include a large thickness of slatey rocks quite unlike any yet found in the Lower Griqua Town beds of Hay and Bechuanaland. Some of the slates, however, are like those shaly beds seen near the top of the Lower group on Rooi Laagte, in Hay (1905 Report, p. 161).

West of Lucas Dam house, the total thickness of the Upper Griqua Town beds is rather over 2,500 feet, provided that the concealed ground does not include rocks with very different dips to those observed. Near the Ongeluk beds there are some 200-300 feet of rather massive brown, red, and black magnetic cherty beds, with which thin blue limestone is interbedded, then follow soft slatey rocks infrequently exposed; about 400 feet above the base of the group is a dull greenish black argillaceous rock with quartz grains and a thin white quartzite; then follow slates, including blue phyllites. Amongst those slates there are obscurely spotted rocks. The contact with the overlying Matsap beds is not exposed.

On Lyn Puts (Mapedi) a similar section can be made out, but there are 200 feet of light-coloured quartzites above the jaspers, in place of the thin bed seen on Lucas Dam. The phyllites are better seen on Lyn Puts; a specimen containing long crystals was sliced for microscopic examination (1664), and it is seen to be made of a doubly refracting ground mass with very much indeterminable dusty material; the crystals are ill-defined, and penetrate each other as if twinned; their substance is replaced by small grains of calcite, two very weakly polarizing minerals, of which one is chlorite in small grains, quartz, and occasionally epidote. Similar rocks with spots and crystals were seen in a corresponding position on Tlhokalechogo, Venn, Tomkins, Murray, and Lewis.

The belt of ground occupied by these Upper Griqua Town beds becomes slightly wider northwards from Floradale, but it is uncertain whether there is a considerably greater thickness of rock between the Ongeluk and Matsap beds there than at Floradale. South of Floradale the superficial deposits hide the boundary for many miles. East of Pauw Fontein there is no room for the Middle and Upper Griqua Town beds between the Lower Matsap and the typical banded jaspers of the Lower Griqua Town group.

VI. The Matsap Series.

This group of rocks can now be divided into three sub-divisions:—

The Upper beds; chiefly quartzites and sandstones, which build up the Langebergen proper.
The Middle beds or Hartley Hill group; quartzites, lavas, and fragmental rocks of volcanic origin.
The Lower beds; quartzites, slates, and conglomerates forming the foothills on the east of the Langebergen north of Pad Kloof.

The work which showed the convenience of introducing this threefold division of the series was done in the south-west corner of Bechuanaland and the north-west of Hay. It is not yet possible to discuss fully the suitability of the arrangement to the rocks as they exist south of Pad Kloof, in the area surveyed in 1905, and in Prieska, but some remarks will be made in connection with that matter.

It will be convenient to describe the occurrence of these rocks under three heads:

(*a*) The outliers in the Koegas Field-Cornetcy.
(*b*) The faulted outlier of the Gamagara ridge.
(*c*) The Langebergen north of Pad Kloof, and the western and eastern foothills.

(*a*) *The Outliers in the Koegas Field-Cornetcy.*

An outlier of the Matsap beds on Dingle forms a prominent ridge, separated by red sand-covered ground from the Ongeluk lavas to the east, and from the Griqua Town beds in the long ridge which trends southwards from Downes to Duikers Dell to the west. The beds dip at 60° towards W. 20° S. They consist of purple quartzitic sandstones containing pebbles of quartz and jaspers, including bright red jasper like that in the Ongeluk beds. As a whole, the rocks are very like the beds of the Langebergen, and the isolated position of this block of apparently Upper Matsap beds requires an explanation which has not been found.

Another mass, eight miles long, extends from Bushman's Hill in a south-south-westerly direction to Spitz Rand. The beds, which are like the Upper Matsap of the Langeberg, dip at angles of 30°-40° towards W. 20° N., and are parallel to the strike of the beds in the Piljaar's Poort hills. The ridge is surrounded by sand, and its structural relations are not clear. The Griqua Town beds crop out within three miles to the south.

(b) The Faulted Outlier of the Gamagara Ridge.

The south end of this strip of Matsap beds was described in the 1905 Report, p. 194, under the name of the Paling ridge.

The ridge extends from Paling about 23 miles northwards to Sishen. The course of the outlier is defined by the Paling fault on the west, which trends N. 3° W., and has its downthrow on the east. The Paling fault can only have a throw of 500 feet or less, except we suppose there was a renewal of movement, but in an opposite sense, along a pre-Matsap fault in post-Matsap times. The difficulty comes in when an explanation is sought for the disappearance of a great part of the Lower Griqua Town beds near the Gamagara valley, where the outcrops of the upper beds are very numerous, though the bottom part of the same group, *i.e.*, the Blink Klip breccia, crops out on the downthrow side of the fault only a mile away. The rocks are ill exposed west of the fault near the Gamagara valley, but there are sufficient outcrops to bring out the fact that a narrow band only of the Griqua Town beds exists there. Further south this strip widens, and at the extreme end of the ridge the Campbell Rand limestone crops out near the fault. It seems to me probable that there has been a renewal of movement along the fault, but in the opposite direction, as supposed above.

The width of the belt of Matsap beds is probably never more than a mile and a half. The dip is generally westwards at angles of from 3° to 30°. Easterly dips are seen on the west side of the belt, and occasionally a shallow synclinal fold is seen, as on King and Mokanning.

The base of the Matsap beds is specially well seen on Mokanning, King, and Bruce. The lowest 20 feet or so of the series are very much redder than the upper beds, doubtless owing to the amount of haematite débris got from the Blink Klip breccia, but there may also have been subsequent staining as well. There are many rounded boulders and pebbles of the heavy haematitic rocks in these lower beds, and in places the matrix of the basal conglomerate is largely made of haematite, so that the outcrop may be mistaken for the Blink Klip rock, but the great difference is that the basal conglomerate contains well-rounded fragments of the breccia, and is distinctly bedded conformably with the overlying normal beds of the Matsap series.

This ferruginous conglomerate resembles closely the exceptional kind of conglomerate seen in the anticline on the Matsap ridge described on pp. 191-2 of the 1905 Report. Similar rocks have not been noticed elsewhere, and they appear to be absent from the south end of the Gamagara ridge on Paling.

The bulk of the Matsap beds in this ridge is very much like the quartzites of the Langebergen; purplish and grey quartzites predominate, but they are not traversed by the rough cleavage that characterises the Langeberg rocks north of Pad Kloof.

It is difficult, if not impossible, to decide which of the three sub-divisions of the Matsap series the rocks on the west flank of the Gamagara ridge belong to. They most nearly resemble the Upper group, but rocks of that type are also found in the Middle and Lower Matsap beds of the Langeberg region.

(c) The Langebergen north of Pad Kloof and the foothills.

At the time the last Annual Report was written there was doubt as to the stratigraphical position of the beds in the foothills both on the east side of the main range on Dunmurray and on the west side south of Witsands. The latter were doubtfully placed in the Kheis series, which, according to Stow, is probably the oldest group in Griqualand West. It was said in that Report that the quartzites and quartz-schists (badly exposed) of the hills south of Witsands were almost certainly older than the Matsap beds. During the past year the western foothills from near Pad Kloof northwards to the Gordonia boundary have been examined, and so have the eastern foothills from Wyd Poort to the north end of the Langebergen. The exposures in Kuruman (*i.e.*, South-western Bechuanaland) are better than those in Hay, and they led me to the conclusion that all the foothills both on the east side of the main range on Dunmurray and same great group which builds up the latter.

The foothills west of the main range on Andries Fontein are made of quartzites and grits, with occasional red jasper pebbles; they are rather more schistose than the Langeberg rocks, but their strike is parallel to the latter. Further south towards Witsands the foothills beds are paler in colour than the bulk of the Langeberg quartzites, but they lie nearly parallel to the latter. They resemble quartzites in the Lower Matsap beds east of the Langeberg. The divergence of strike south of Matsap noted in last year's Report is not yet explained. The rocks only crop out in the ridges along here, and on the east of the main range the same is the case. Intervening low ground from half a mile to four miles wide is sandy, and wells are very few, so the structure is difficult to make out. Till the country west of the main range is fully traversed the question of the precise stratigraphical position of the western beds must remain open. The dip of beds in any one ridge does not help much, for the rocks in the main range are repeatedly folded, and the foothill beds are also folded; so that unless a nearly continuous section can be found the isolated dip observations do not settle relative stratigraphical positions.

In the last Annual Report it is stated that jasper pebbles were not obtained *in situ* in the conglomerates seen near Lucas Dam, but further examination has shown that such pebbles are present, and that in some localities they are fairly abundant.

About 400 yards south of the gate on the west side of Lucas Dam, and situated on the farm M. 104 (part of the Dunmurray estate), there are three bands of conglomerate in the Lower Matsap beds exposed by a long cutting. The matrix of the conglomerate is quartzite, and the intervening beds are chiefly reddish and greenish quartzites and grits, but there are also sandy slates and silky phyllites. The pebbles in the conglomerates are in most cases quartzite and quartz, but there are also pebbles of red jasper, a dark green diabasic rock, and a granite with large flakes of muscovite. The sandy slates and phyllites are not exposed on the hillsides generally, for they are covered with fallen débris from the hard beds. The quartzites below the conglomerates are usually light in colour.

These easternmost foothills rise to a height of about 1,000 feet above the flat ground to the east of them on the western side of M. 91 (Hay) and Mapedi (Lyn Puts) in Kuruman. They form a range stretching from Young in Kuruman, about 40 miles southwards, to O. 231 in Hay, but there are gaps where the rock sinks below the sand at several places in their course, and south of O. 231 they are not seen again, unless one of the outlying ranges in the Koegas Field-Cornetcy represents them. North of Young they do not appear, but from the top of the Langebergen near Toto I saw similar foothills east of the Korannaberg.

On the eastern side of O. 209 (Pauw Fontein), some 20 miles S.S.W. of the last appearance of the foothills, prospecting trenches have been made in gently undulating gravelly ground, and in one of these two bands of coarse quartzite conglomerate have been exposed; they contain pebbles of quartz, quartzite, and red jasper. The conglomerates are from three to four feet thick, and are interbedded with quartzites and green schistose slates; they dip W. 20° N. at about 45°, towards some volcanic rocks exposed in a cutting west of them. They are almost certainly part of the Lower Matsap group. The change of strike, which is about N. 5° E. near Lucas Dam, agrees with the similar change in the main range noted in the last Annual Report; N.N.E. at Bakens Kop, and more and more nearly north towards Andries Fontein.

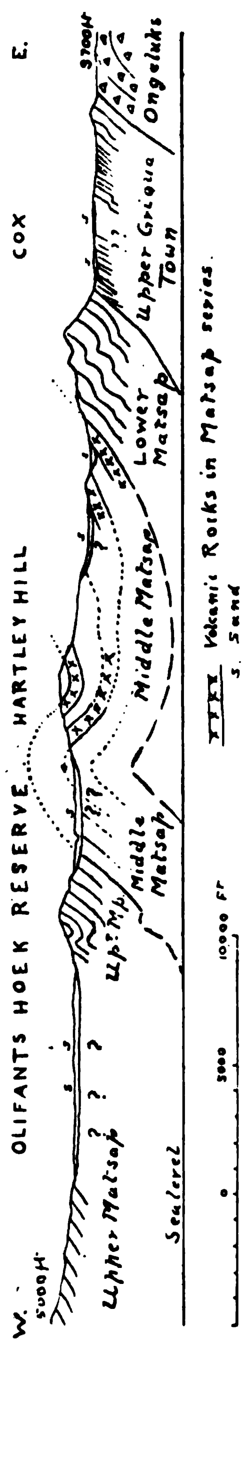
As explained when dealing with the Upper Griqua Town beds, there is difficulty in drawing a boundary between the latter and the Matsap group in northern Hay and southern Bechuanaland, for the Upper Griqua Town beds are ill exposed, and the strikes of the two series are nearly or quite parallel. It is certain, however, that in the south of Hay, as well as in the Paling and Matsap ridges, the Upper Griqua Town beds do not intervene between the Matsap beds and whatever happens to underlie them. At the present time the Middle Matsap beds have not been recorded south of Paauw Fontein, so that there is a doubt as to the identity of the base of the Matsap series throughout

Hay and Prieska. It is likely that the line taken as the base of the series in the eastern foothills last year, *i.e.*, the bottom of the first quartzite or grit met with when going westwards from the jasper and slate rocks of the Upper Griqua Town beds, will be found to be very near the true base in this area.

The strike of the Lower Matsap beds on Paauw Fontein is N. 20° E., where next seen on O. 231 it is N. 150° E., on Vogel Water it is N. 10° E., on Lucas Dam N. 50° E., north of the Bechuanaland fence on Mapedi it is north and south, but on Tlhokalechogo it turns to N. 5°-10° W., on Mamatlui, Tomkins, and Hartley it remains about N. 10° W., but in the low kopjes in which the formation makes its last appearance, so far as last year's work was concerned, on Neylan, Cox, and Young, the strike is about N. 25° W. This general bending of the strike corresponds closely with the bending of the Langebergen a few miles to the west.

The thickness of the Lower Matsap beds in the north part of Hay cannot be less than some 3,000 feet.

The line dividing the Lower from the Middle Matsap beds is drawn below the lowest lava or distinctly ashy rock, and the line between the Middle and Upper beds is drawn at the top of the highest lavas or ashy beds. The quartzites included between these limits are in part white and green, and these beds are unlike the great mass of rock forming the Upper Matsap beds as defined here; but there are purple grits and quartzites also, probably these are thicker than the green and white beds. If the volcanic rocks disappear along the strike there will be no means of distinguishing the three sub-divisions, except by the presence of slates and conglomerates in the lowest sub-group.



Difficulties of this sort must always be encountered where lithological characters alone are taken as the basis of classification, but it seems better to make use of such characters in a thick group of rocks like the Matsap series than to leave the series undivided.

The Middle Matsap beds are best seen on the Olifants Hoek Reserve and Hartley, where their outcrops are repeated by folding. They have been followed 9½ miles north of Olifants Hoek, as far as the farm Dalgetty, and the outcrops are fairly numerous in that direction. South of Olifants Hoek they have been traced at moderate intervals as far as M. 102 in Hay, but from there only one outcrop was seen, on O. 231, till the southernmost exposures, in 4 prospecting pits, are met with on O. 209 (Pauw Fontein). If intervening outcrops exist they are cut flat with the plain east of the Langeberg in this region. The whole distance from Dalgetty to Pauw Fontein is about 60 miles.

The best exposures near Olifants Hoek are on the hills between that Reserve and Hartley. The section in Fig. 7 shows the general relations of the volcanic rocks and the quartzites, etc. There are wide stretches of concealed ground in the course of this section, but less than along any other line that I could

FIG. 8.—Section through a hill about 300 feet high in the north-east part of Olifant's Hoek Reserve.

1. Blue lava
2. White quartzite.
3. Blue lava.
4. Blue gritty tuff.
5. Green quartzite.
6. Blue lava.
7. Blue tuff.
8. Blue lava.
9. Blue-green tuff.
10. Green quartzitic tuff.
11. Blue-green breccia and tuff.
12. Purple quartzite.
13. Sand.

have examined. The section is drawn approximately to scale, and the thicknesses of some of the various rock groups as represented are not far from the truth unless there are undetected faults which increase the apparent thickness; folds will do the same, and in great bodies of uniform rock, as that on the west of the section, folds are difficult to discover, and it is impossible to gauge their effect without making a detailed survey. The Upper beds, therefore, are certainly not so thick as they appear in the section.

There are two volcanic bands in the section; but each of these has more usual types of rock in it.

The section in Fig. 8 represents the structure of a hill on the north-east part of the Reserve, where the intercalation of lavas, ashes, and quartzites is well seen.

On the east side of Hartley the Middle group is seen lying on the quartzites and conglomerates of the Lower group. It commences with a coarse conglomerate which has a dark green ashy matrix; this conglomerate is several feet thick, and above it are less conglomeratic beds; all these are well bedded rocks. Above them lie dark green breccias, which do not contain the quartzite, quartz, and jasper fragments seen in the conglomerates below, and lavas. There are some 600 feet of the lavas and breccias exposed, and the conglomeratic beds below, together with interbedded quartzites, bring the thickness of the part of the Middle Matsap beds exposed on these hills up to nearly 1,000 feet. These beds are separated by sand from the nearest outcrops westwards of them, and the greater part of the Lower Matsap beds is hidden on this, the eastern, limb of the Hartley hill syncline. An interesting section shows the gradual passage from green breccia or tuff into the usual purplish quartzites of the Matsap series. A slice cut from a piece of the transitional rock (1665) shows much quartz and chert in well-rounded grains up to 2 mm. in diameter. The matrix is made of epidote, chert, calcite, and dusty matter like powdered devitrified glass. There are pieces of scoriaceous devitrified glassy lava nearly opaque with this dusty matter.

The gritty quartzites of this neighbourhood and the green ashy beds are affected by a rough cleavage, which trends S. 15° W. The cleavage is like that seen in the main range of the Langebergen, and it obscures the dip, for the rock yields to weathering along it rather than along the bed planes, which strike in more or less the same direction, but have a much lower inclination than the cleavage. In spite of the cleavage, the synclinal structure of the Hartley hill rocks is well seen from the north; and the dark ash beds and lavas bring out the structure very clearly in certain parts.

At the north end of these hills, near the north-eastern beacon of the Reserve, the volcanic rocks are well exposed. The beds represented in the section Fig. 8 belong to the lower of the two volcanic bands, and are almost certainly part of the beds lying just above the basal portion of the Middle Matsap group described above. A slice cut from the uppermost tuff (11 in Fig. 8) shows (1667) round grains of quartz, chert, and felspar lying in a rather opaque green matrix, which contains also recognisable plagioclase felspar laths; the bulk of the matrix cannot be separated into its constituents under the microscope, but chert and epidote are distinguishable, and a great quantity of very small needles of a greenish mineral, and also opaque iron ores. A slice of a vesicular lava (8 in Fig. 8) shows much blue-green hornblende in allotriomorphic crystals, partly changed to a

chloritic mineral, faint outlines of the original felspar laths, now much altered, iron ores and sphene, chert, epidote and actinolite. The last two minerals are products of the alteration of the original constituents; the chert may be an addition from outside; and together they now make up the bulk of the rock. The vesicles are filled with chalcedony, epidote, and calcite (1668). The volcanic beds of this hill are separated by some 500 feet of quartzites from the higher band of volcanic rocks exposed on the face of the high hill east of Olifants Hoek Police Camp. The lowest green beds are ashes; as in almost all of the Matsap ash beds, a conspicuous feature on a broken surface is made by the fractured quartz grains plentifully scattered through the rock; they are as much as 1-2 mm. in diameter, and they are well rounded; there are similar grains of chert and a few of felspar, which looks like a felspar from granite, for it is either twinned acid plagioclase or microperthite. There are small pieces of vesicular lava with calcite and chloritic amygdales; the finer grained part of the rock is a mixture of epidote, calcite, and chert (1662). Two slices have been cut from lavas exposed on this hill (1623, 1625), but there hardly any of the original characters of the constituents are recognisable. The rocks are made of epidote, chert, actinolite, sphene, and a little calcite. Some iron ores are the only constituents which may be original. The steam holes are filled with epidote, chalcedony, and chlorite.

A slice (1624) from a vesicular lava fragment taken from a breccia on this hill shows the outlines of felspar laths now represented by chlorite, calcite, and cherty silica lying in a green matrix clouded with dusty matter. The vesicles are filled with chalcedony and epidote.

North of Olifants Hoek it seems probable that the syncline shown in Fig. 7 disappears, and that there is a more or less continuous upward succession from the base of the series on Lewis to the middle of the main range near the trigonometrical beacon Langeberg (6,011 feet). That this is probably the case is shown by the narrowing width of the ground which the Lower and Middle groups occupy as one goes northwards from Olifants Hoek. On O'Donoghue the lower part of the volcanic beds is buried, but amygdaloidal and compact lavas and ash beds are seen. A slice from one of the lavas (1669) shows rather large ill-developed crystals of blue-green hornblende, often twinned on the orthopinacoid plane; no felspar is visible, and the bulk of the rock consists of chert, epidote, actinolite, and small grains of sphene.

On Puduhuish, Toto, and Dalgetty there is a range of kopjes made of volcanic rocks, but their position in the series is not certain. The best section is probably seen on Puduhuish, where the lowest visible beds are cleaved sericitic quartzites containing a few massive beds without sericite; small quartz pebbles occur in these quartzites. Above the quartzites lie 600 feet of gritty

dark breccias and tuffs, then come 70 feet of quartzites with pebbles, overlain by 250 feet of dark-coloured lavas, breccias, and a few bands of quartzites, 400 feet of tuffs and lavas complete the section as far as the volcanic rocks are concerned; some 200 feet of purple quartzites are seen above the volcanic rocks, and a wide flat devoid of outcrops lies between the westernmost kopje and the Langeberg.

South of Hartley and Olifants Hoek the Middle Matsap beds are exposed on Gaston and Tomkins, and again on Mamatlui; the rocks are much hidden on these farms, but a well sunk on Mamatlui reveals a coarse conglomerate, with boulders and pebbles of quartzite, red and black magnetic jaspers, quartz, slate, and green diabase in a tuffy matrix. Outcrops of amygdaloid and tuff occur within 200 yards of the well.

Further south the Middle group makes outcrops on M. 102, where a low ridge of volcanic rocks projects from the sand. The lowest rocks seen are blue-green epidotic lavas and tuffs, above which lie grey quartzites about 4 feet thick, with numerous boulders of quartzite, chert, and lavas up to a foot in diameter, all well rounded; 200 feet of blue porphyritic lavas lie on the conglomerates, but no further outcrops were seen till the usual purple quartzites of the series were met with about half a mile to the west. The porphyritic lava is unlike any rock in other outcrops of this group yet examined; a slice (1663) shows that the felspar crystals are completely altered into a mass of minute minerals; the ground mass shows faint indications of the original small felspar crystals, but it is now made almost entirely of chert, epidote, actinolite, and calcite. A few quartz grains occur; they are angular or quite rounded, just like the quartz grains in the Matsap tuffs and quartzites; they were probably picked up by the lava or dropped into it during its flow, and are not the remains of corroded porphyritic quartz crystals.

The conglomerate is seen under the microscope (1661-2) to consist of rounded masses of chert, lavas of the types found in the Matsap volcanic series and described above, and a few pieces of marble embedded in a gritty matrix in which round quartz grains are conspicuous; the fine grained part of the matrix consists of epidote, calcite, actinolite, and chert. This rock was evidently derived from the waste of a volcanic area, and could hardly have been formed unless there was a land made of the Matsap volcanic rocks; so it proves a local unconformity, unless the volcanic rocks extended beyond the range of the quartzitic sediments, and thus provided débris during and after the eruptions. At the present time no evidence has been found of a considerable unconformity within the series.

The volcanic rocks crop out again about a mile north of the road from Dunmurray to Floradale, on the farms M. 100 and O. 231. Some 500 feet of green amygdaloids and fine tuffs like

those of Olifants Hoek are seen here. The outcrops are separated from the purple quartzites to the east and west by wide strips of sand.

The southernmost exposures of the volcanic rock yet found are on O. 209 (Pauw Fontein) and O. 212. They are in cuttings north-west of the conglomerates mentioned on a previous page in connection with the Lower Matsap beds. Two sections (1658, 1659) have been cut from the lavas on Pauw Fontein; they are from amygdaloidal rocks, the vesicles being filled with chalcedony, chlorite, and epidote; felspar is present in partly altered lath-shaped sections of small size, it has low extinction symmetrically about the twin plane; the rest of the rock consists of epidote, chert, and iron ores in very small grains; there are no porphyritic constituents.

No important details as to the stratigraphical position of these lavas are available, but the fact of their occurrence west of the westward dipping conglomerates, quartzites, and phyllites of the other cutting is enough to show that they belong to the Middle Matsap group as defined above, and they are similar in character to the Olifants Hoek and Hartley lavas.

The thickness of the Middle Matsap beds is very considerable, perhaps as much as 4,000 feet.

Comparison of the volcanic beds of the Matsap series with those in the Griqua Town series and the Ventersdorp beds.

As there are now three great volcanic groups older than the Karroo system known from the country north of the Orange River, it is desirable to point out briefly the chief characters that distinguish the Matsap lavas from those belonging to the other groups. So far as the Matsap lavas are yet known, they are the most altered of the three, although they are the youngest. They are decidedly less acid in composition than the Pniel rocks, which are again much less acid than the Beer Vley and Zoetlief lavas. They contain little, if any, original quartz, the cherty silica now seen in them is very probably all of secondary origin, whereas the Ventersdorp diabases very frequently contain quartz in micropegmatite, and the more acid lavas (Beer Vley and Zoetlief) have quartz crystals porphyritically developed, as well as quartz in the ground mass. The Matsap lavas are unlike those of the Ongeluk group both in having no pyroxene phenocrysts and in the nature of the ground mass, though the former are so greatly altered that a former glassy or andesitic base may not be clearly recognisable. The few specimens which show remains of small felspar crystals indicate that the ground mass may have been of the sort called andesitic.

The presence of blue-green hornblende in two of the lavas examined would seem to separate them from the older lavas. This hornblende looks like an original mineral and not uralitised augite.

No analysis has been made of the Matsap lavas, and their great alteration makes it impossible to give them a name which has a precise signification, but they seem nearer the hornblende-andesites than any other large group of rocks.

As in the cases of the older volcanic beds, there is as yet no indication of vents or fissures through which the Matsap lavas and tuffs were extruded.

Mr. Mellor[1] has described volcanic rocks from the Waterberg system of the Transvaal, of which the Matsap beds are supposed to be the equivalent. It is obvious from the accounts referred to that the Transvaal volcanic rocks of this age are more acid than the Matsap volcanics; nothing approaching a rhyolite has been found in the latter.

The Upper Matsap beds form the main range of the Langeberg and some large hills lying east of it, such as those on Makala, Thabaletseli, Dunmurray estate, and Wyd Poort. They consist of a thick mass of very uniform quartzitic rock, purplish in colour, containing scattered pebbles of quartz and jasper. The chief difference between parts of this rock is brought about by the presence of more or less argillaceous and sericitic materials, but these do not occur abundantly enough to give rise to slates or phyllites; the quartzites become distinctly cleaved where there is a perceptible amount of the sericitic or clayey matter. In many sections false-bedding is strongly developed.

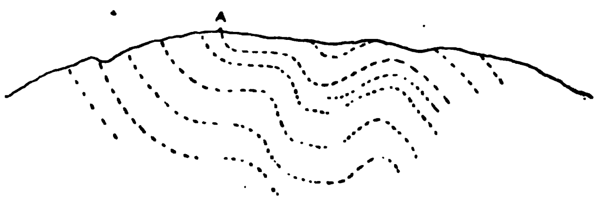


FIG. 9.—Diagrammatic sketch of the hill on which the Trig. beacon Langeberg (A) stands (6,011 feet), showing the flexures in the Upper Matsap beds. Drawn from the hill to the north which reaches about the same height.

Where a large steep slope can be seen, as on Puduhuish near the Langeberg beacon (see Fig. 9), large folds can be clearly seen. Similar sections, but not on such a large scale, are exposed in several kloofs south of Andries Fontein. Generally, however, the folds are not visible, and very detailed work, which cannot be undertaken at present, will be required before the course of the beds can be accurately laid down on a map or on a transverse section across the range. The difficulty is to recognise beds again after losing sight of the outcrop. There can be

[1] Rep. Geol. Surv. of the Transvaal for 1904, p. 56; 1905, pp. 87-89. Trans. Geol. Soc. S. A., Vol. VIII, 1905, p. 38, etc.

no doubt that the whole range from Pad Kloof to Matesang is made of folded beds, and therefore of a thinner group of rocks than one would suspect from several traverses, when occasional good outcrops alone are seen. The rough cleavage dips westwards and tends to obscure the dip of the beds.

VII. THE DWYKA SERIES.

The Dwyka series is the only member of the Karroo system (excepting intrusive dolerite) found in the area we are now concerned with. It occurs on the east of the Griqua Town escarpment, south of the village of that name, in the wide valley east of the Langeberg, near Pad Kloof, and near Vryburg; the last-named locality was described by Mr. du Toit in the 1905 Report.

East of the Griqua Town escarpment the Dwyka beds were only seen in the valley of the Sand River, which runs south-east to the Orange River; they there form part of a large area lying to the east, and but little information was got about them. They certainly lie upon the Campbell Rand and Griqua Town series at a somewhat lower level than the general surface of the Kaap Plateau. The interesting question as to whether this Plateau is a feature dating from pre-Karroo times or whether it is entirely subsequent to that formation could not be answered from the limited area examined, but the apparently flat surface formed by tufaceous limestone of recent date, and passing from the Dwyka on to the much older rocks, gives the impression that the southern part of the great plateau is a result of post-Karroo erosion. Dwyka outliers, either lying on the flat surface of the plateau or filling valleys in it, have not been found in the country between Griqua Town and the northern edge of the plateau. On Middelwater and Elands Fontein the Dwyka boulder beds contain great numbers of dolomite and lava (Pniel series) boulders up to 5 feet in length, and a few of granite. An exposure of the underlying surface in the immediate neighbourhood of the Dwyka was not seen.

In last year's Report (p. 196) an outlier of boulder grit was described from Piljaar's Poort, in the south of the Langebergen. A much larger outlier, of which the boundaries cannot be laid down owing to the presence of a thick sandy soil, occurs on Plaatjes Dam, near Pad Kloof, and extends northwards at least as far as Pauw Fontein (O. 209). Evidence of the occurrence of boulder beds was only seen on Pauw Fontein, where a well, now filled in, had been sunk on them, and pieces of typical mudstone, with pebbles of various rocks, together with a few scratched stones, lie about the spot. About half a mile west of the filled up pit another well is down 50 feet in yellowish shales, but the boulder beds were not reached. At Plaatjes Dam a well was dug 100 feet into grey shales lying horizontally without reaching

the bottom ; on the right bank of a stream bed from the Langebergen similar horizontal shales are exposed, and they contain thin layers of fibrous limestone, with the fibrous structure perpendicular to the bedding. Limestone of this character is met with in the Dwyka formation in the Vaal River[1] valley and in the south of Cape Colony. There is little but the mere occurrence of these rocks to record, but they show that in Dwyka times the valley east of the Langebergen in this neighbourhood was deeper than it now is, and that the existing wide and flat valley is cut out of pre-Karroo rocks as well as those of Dwyka age, for the Pauw Fontein Matsap outcrops mentioned on a previous page are on about the same level as the top of the wells in the Dwyka formation, or only slightly higher.

VIII. Intrusive Rocks.

There are many dykes and a few other bodies of intrusive igneous rocks in the area surveyed. No intrusions of typical acid rocks, such as granite, were found; the granite described on a previous page may be called the basement rock of the district, and the sedimentary beds which it invaded have not been found within the district.

It will be convenient to describe the rocks according to their petrographical type, as it is not possible to decide with certainty the age of several of them. In fact, in no single case can the age be determined precisely, for a later limit is difficult to ascertain. The petrographical character of certain masses enables one to say that they belong to the same great group as the intrusions which occur in the Karroo formation throughout a very large area in the Colony; and the nature of other intrusions shows that they belong to the Pniel, Ongeluk, or Matsap volcanic groups.

(1) *Basic and intermediate rocks other than Karroo dolerites.*

In the Middle Matsap beds near the north-east corner of Olifants Hoek there is a small but conspicuous mass of a rather coarse-grained quartz-diabase. Though associated with the Matsap volcanic rocks, its characters are so different from those of the lavas that it cannot at present be regarded as belonging to the same group of rocks. Beyond the fact that it is intrusive in the Middle Matsap beds, its age has not been fixed. It differs considerably from the Karroo type of dolerite. It forms a short thick dyke about half a mile long and some 300 yards wide, trending east and west, but slightly concave towards the south. A thin section (1666) shows that it is of felspar, augite,

[1] R. B. Young. "The Calcareous rocks of Griqualand West." Trans. Geol. Soc. S.A. Vol. IX, p. 63. Said there to be in the Ecca series, but these beds at Schmidt's Drift, etc.) belong to the Dwyka as defined by the Cape Survey.

hornblende, quartz, ilmenite, sphene, apatite, and alteration products. The felspar is of two kinds; one variety, which occurs in stout crystals, with partly idiomorphic outlines, is almost entirely changed to a mass of epidote, zoisite, sericite, and some colourless weakly polarizing mineral, but a few patches are left, in which twin lamellae are seen; these crystals are surrounded by untwinned fresh felspar, which is often in optical unity with the felspar in neighbouring areas of micropegmatite. The latter, together with quartz without intergrown felspar, forms a considerable part of the one slice cut. The augite is cloudy, owing to the great development of a fine basal striation; it occurs in irregular patches, which do not enclose the felspars; it is often edged with green strongly pleochroic hornblende. The latter mineral also occurs alone, and in that case shows prism faces in some instances; it is certainly an original constituent. Sphene, ilmenite, and apatite are fairly abundant. The ilmenite occurs in patches with a reticulate structure, plates of ilmenite intersect each other at 60°, and the interstices are filled with a semi-opaque mineral like that called leucoxene. No mica is visible, but some chloritic pseudomorphs look as if they represent biotite. There are also pseudomorphs of chlorite and actinolite after augite. Epidote is abundant.

A thin dyke of compact dark blue rock traversing the Middle Matsap beds on Olifants Hoek is seen in thin section (1621) to consist almost wholly of felspar and blue-green hornblende. The felspar occurs in two ways, in small laths in the ground mass and in larger porphyritic crystals. The symmetrical extinction angles on albite-twins reach 20°. The hornblende is a pleochroic bluish-green variety, like the original hornblende in the Matsap lavas; it does not show crystal faces, but it occurs in small areas between the felspars, often being applied to them as the augite is in ophitic dolerites, though the hornblende in this rock is never in large enough patches to enclose the felspar. Iron ores and sphene are present. The rock is certainly allied to the Matsap lavas.

A coarse gabbro-like rock occurs as an intrusion in the Campbell Rand series on Klip Fontein, Hay. It is exposed in a prospecting hole, and its shape cannot be seen. The specimen examined is much altered, though it came from 50 feet below the surface. In a thin section (1610) it is found to consist of generally irregularly shaped pieces of colourless augite, embedded in a mass of saussurite. The original felspar is no longer visible. The augite occasionally shows partial crystal boundaries; it is in almost every case bordered by an edge of colourless amphibole, which often encroaches on the augite along cleavage cracks. Iron ores are the only other original constituent seen.

Intrusions related to the Pniel lavas and those of the Ongeluk beds have been noticed, and in part described in connection

with those rocks (see pp. 17, 46.) In the areas mapped in as Ongeluk beds, there are probably many intrusions included, for the intrusions and lavas were not separated in the field. Their separation would require a re-examination of the ground, with a good knowledge of the characters of the various rocks under the microscope.

(2) *Karroo Dolerites and Related Rocks.*

Throughout nearly the whole of the large area in Cape Colony covered by the Karroo formation, intrusions of dolerite are met with; the rock is found both in dykes and sheets, but the latter form is the more abundant, at least as regards quantity. North of this area the dykes predominate, in fact, only two groups of dolerite outcrops in Hay and Bechuanaland can be regarded as belonging to a sheet; one of these occurs on Dunmore, in Hay, and the other was found on Durham, near Groot Fontein, on the Kaap Plateau, between Taungs and Kuruman. The latter forms a roughly circular area, about 1½ miles in diameter, and there is a pan on it. Whether it lies above or below the surrounding beds of Campbell Rand limestone is uncertain. A contact with that limestone is seen in a shallow pit on the east side of the dolerite, where white marble is exposed on one side of the pit and dolerite on the other. The junction for a foot or two at this place may be vertical. The rock (1613) is a rather coarse ophitic olivine-dolerite, with some biotite and a very small amount of brown hornblende. There are a few interstitial patches of devitrified glass. This rock does not contain quartz or the micropegmatite often seen in the less basic varieties of tne Karroo dolerite.

Dykes of dolerite are found almost throughout the district, but they are specially noticeable in the Campbell Rand formation. Sometimes they crop out freely, but more often they are marked on the surface by limestone " aars." " Aar " is the name used by the Boers for any feature on the surface which is very long compared with its breadth. Thus it may be applied to the outcrop of a dyke, to a low ridge of limestone, like those to be described presently, to a slight depression, probably marked by rather different soil from the surrounding veld, or to a line of country characterised by a particular kind of bush, and not easily distinguished by a stranger in the district. They are looked for and followed, because experience shows that water is usually got at shallower depths on or near an aar than elsewhere, and a large proportion of the springs occur on aars. I have not heard the line of junction between two stratified formations called an aar.

Limestone aars are often seen during a traverse of the Kaap Plateau. In some cases they may escape the notice of a stranger, but they more often attract his attention. They are low

ridges rising from 5 to 20 feet above the general surface, and they are often marked by a denser growth of thorn trees and bushes than is found on the neighbouring veld. White surface limestone almost always crops out on them, or is seen where a track crosses them. I have seen many pits and cuttings which expose from 3 to 10 feet of loose white surface limestone in the aar. It is rarely that the cause of the aar is at once found, but on making a search by walking a mile or two along an aar, fragments or outcrops of a dyke rock such as dolerite or diabase are met with in many cases. This happened in my experience so constantly in tne area occupied by the Campbell Rand beds that I now regard an aar as good evidence of a dyke. Travelling from Taungs to Kuruman (about 95 miles), one sees the first aar, lying E. 10° S., near Baas Jan, dolerite outcrops were found along it; three aars trending a few degrees east of north pass through Marea Amoet and one or more of them stretches far to the south and north; to tne north it is probable that the aar which runs from Rooi Pan to Lochnagar is an extension of one of these Marea Amoet aars, though it has not been traced continuously over the 50 miles of country; dolerite outcrops were found on all of these aars. A S. 34° W. aar runs through Gakwe, and a north-south one through Schiet Fontein; outcrops of a dyke rock were not seen on these, but a short search only was made. An aar with dolerite outcrops passes north and south through Kent and Charles Puts; an E. 20° S. aar goes through Groot Fontein, and Mr. Mayers told me he had seen it on certain farms as far east as the edge of the escarpment in Barkly West; on the map this line was found to be nearly a continuation of the observed trend on Groot Fontein, where dolerite is exposed in pits along the aar; the dyke therefore probably has a length of at least 30 miles. Another aar with outcrops passes N. 20° E. through Toxteth.

In the Maremane anticlinal area an aar with many outcrops was followed for 21 miles north-north-east from Postmasburg, and a similar one seen on the same line six miles further north on Mount Huxley and Maremane is probably a continuation. Two other aars were seen on A. 23 in the same neighbourhood. The north of this area is so deeply covered with sand that aars could not be expected.

The reason why low ridges of surface-limestone accompany many dykes in the dolomite areas is that the dykes check the flow of underground water, and furnish a means whereby that water reaches the surface more easily than elsewhere; on evaporation the dissolved carbonate of lime is deposited, and as all the water here must contain lime, a larger amount of surface-limestone is formed than elsewhere in the immediate neighbourhood. Any other line along which water finds a ready passage to the surface should be similarly marked, so a fault in the

dolomite should give rise to an "aar." Whether there is such an aar is not yet known. The only aar known to me along a fault, that of Lochnagar, is also along a dyke.

Thin sections have been cut from some of the dyke rocks. The Postmasburg dyke was referred to on p. 199 of the 1905 Report, but the nature of the rock was then uncertain. A section of the rock from Pens Fontein shows it to be an ophitic dolerite without olivine; it is quite fresh; labradorite and augite are the chief constituents, but iron ores, biotite, and brownish-green hornblende are also present, the two last named in very small quantity.

The three dykes on Marea Amoet are made by rocks of a similar nature to that just described, but they are not so fresh and they contain micropegmatite. The middle dyke of the three (1576) is the freshest, and has the smallest amount of micropegmatite in it; it contains both biotite and brown-green hornblende; the eastern and western dykes (1577 and 1575) have rather more biotite and hornblende.

Near Daniels Kuil there are at least two dolerite dykes. Sections from these on Klip Vley shows one of them (1579) to be a dolerite without olivine, and the other (1580) to be an olivine-dolerite, in which olivine is replaced by serpentine. (1580) is a very fine-grained rock, and the augite is partly in the granular form, i.e., the ophitic structure is not so far advanced as in most of these rocks. (1579) is more weathered than the other, but less than the Marea Amoet dykes.

Near Klip Fontein, on A. 23, there is a dyke of a remarkable rock, rather coarse grained, with pink felspar in it. No fresh outcrops were found, but good specimens were obtained from a prospecting shaft sunk 50 feet into the dyke. Three slices (1607-9) have been cut from it. It is a holocrystalline, rather coarse-grained rock, made of felspars, hornblende, quartz, augite, biotite, iron ores, and apatite, written in the order of their relative abundance, together with alteration products. Apatite is the only mineral which often shows crystal faces. The felspar is of two kinds, one is now much decomposed and represented by areas of cloudy material, crowded with small brightly-polarizing flakes; this pseudomorphic substance is usually surrounded by a narrow zone of clear felspar, which is occasionally twinned on the Carlsbad law, and is probably orthoclase; it is intergrown with quartz at the periphery in several cases. The other felspar is less altered and less abundant; extinction angles on the twin-plane trace in sections perpendicular to that plane range up to 17°, and it is probably oligoclase. It sometimes has its proper crystal faces, and projects into all other constituents, except iron ores and apatite. Quartz is fairly abundant and was the latest constituent, together with the felspar in micropegmatite, to solidify. The hornblende is a green, strongly pleochroic variety, and is more plentiful than augite, which occurs

in patches in parallel crystallographic position with the hornblende. This hornblende is an original constituent; uralite occurs as an alteration product of the augite. The original hornblende also forms intergrowths with the iron ore. Biotite is present in small quantity in the slices cut, but it is in rather large plates, which are mostly converted into chlorite. Chlorite and epidote are the most frequent alteration products.

This rock is more like the quartz-mica-augite diorite that forms the Transkei "gap" dykes[1] than any other known to me, but the pink orthoclase gives it a different appearance to the naked eye. In thin section the two rocks are much alike, though the augite and mica are less abundant in the Klip Fontein than in the Transkei dyke, and sphene, a conspicuous constituent in the latter, was not noticed in the former. There is no direct evidence as to the age of the Klip Fontein dykes, other than its intrusion through the Campbell Rand series. Its similarity to the later intrusions in Kentani points to its belonging to the Karroo intrusions.

Dolerites have been found cutting through the Griqua Town beds on M. 36, Hay, near the Peiser mine, on Dunmore and on the eastern side of Lucas Dam, in the Upper group.

The rock obtained from a prospecting hole on M. 36 is probably part of a dyke; a section (1470) shows it to be a typical moderately coarse-grained fresh ophitic dolerite, without olivine, but containing brown mica and a very little green hornblende.

On the south end of M. 57 there were two specimens of rock taken from an outcrop, and from a pit near the outcrop. They are both Karroo dolerites (1467, 1468). The outcrop rock is a fresh ophitic dolerite, without olivine, but the other is a very fine-grained dolerite, in which the structure is porphyritic, owing to the presence of some felspar crystals of the size found in coarser-grained dolerites, while the augite is in small grains.

The rock from Dunmore was collected as an example of a bed of lava or fine-grained tuff, about 50 feet above the base of the Ongeluk volcanic series, but a thin section (1597) shows that it is a fresh and very fine-grained dolerite of the Karroo type, with granular augite, an entirely different kind of rock from the lavas of the neighbourhood. It came almost certainly from an intrusive sheet, of which the nature was not realised during the field work, and which is not laid down on the map. Under the microscope this dolerite is seen to contain some small patches of serpentine, but no mica; its structure is like that of the fine-grained rock on M. 57.

The only intrusive rock met with in the Matsap series of similar type to the Karroo dolerites was obtained from a well on Neylan. No outcrops were found. It is a very coarse labra-

[1] Ann. Rep. Geol. Com. for 1901, p. 64 and Trans. S.A. Phil. Soc. vol. XIV Part I.

dorite-augite rock, with small quantities of biotite, green hornblende, apatite, iron ores, and micropegmatite. The hornblende either fringes the augite or is enclosed by it. Only a very small amount of micropegmatite is present. The augite is partly ophitic, but occasionally a crystal face is seen. Two slices were cut from the rock taken from the one well, one (1619) is very fresh, and the other (1620) has rather cloudy felspars and augite, and its mica is greenish.

No intrusions were met with in rocks younger than the Matsap beds, but the Karroo sediments occupy such a small area that the absence of dolerite intrusions from them is of no significance.

IX. Superficial Deposits.

In many parts of this district the solid rocks are buried more or less completely under various surface deposits, which may attain a considerable thickness. A sub-division of these deposits according to their age is not yet possible; some of them are obviously in process of formation to-day, others may be of considerable antiquity. It will be convenient to describe them according to their lithological characters:—

(1) Sands.
(2) Surface quartzites and ferruginous rocks.
(3) Gravels.
(4) Limestones and associated siliceous rocks.

It will be seen that these four classes of rocks cannot be separated strictly, for there are transitional varieties between all of them.

(1) *Sands.*

In almost all parts of the district there are areas covered with sand or sandy soil, but the sand becomes more and more abundant as one travels westwards towards the Langebergen, though there are stretches of fairly level country along that range where there is but little sand.

On the Kaap Plateau not much sand is seen near the eastern escarpment, but it becomes abundant about half-way across and in the northern portion. The sand in this area is generally yellow in colour; red sand is usually met with within some ten miles of the Kuruman-Asbestos range.

On the farm Put Pan near Geluk a long water-cutting has been made through the surface deposits, and for a considerable distance the underlying rock, thin shaly beds belonging to the Campbell Rand series, has been reached. The section thus afforded is the best exposure of the sands, etc., on the Kaap Plateau that I have seen. The two sketches in Figs. 10 and 11 show the different layers exposed at places in the cutting about 400 yards apart. The surface is part of a wide grass

plain, the soil at the top is scarcely distinguishable from the loamy material on which it rests, but it has more dead vegetable matter in it than the underlying sand. The sand contains a considerable amount of clayey matter, and is evidently akin to loess, it is yellow in colour and may be 15 feet thick, perhaps more, for at a distance of some 1,500 yards from the water-hole the cutting does not cut through it. It has a rough vertical jointing, and is of such consistency that the perpendicular sides of the cutting do not fall in rapidly; they have stood uninjured in many parts for more than three years. There are irregular tubes of small diameter in the sand made by roots passing more or less vertically downwards. The sand is almost free from rock fragments at a distance of 10 feet or more from the shale floor,

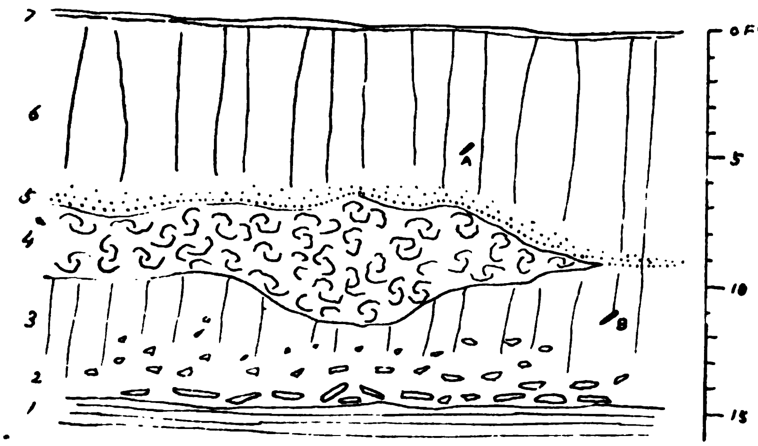


FIG. 10.—Section exposed in water-cutting on Put Pan. 7. Surface soil scarcely different from 6, but containing dead grass, etc. 6. Yellow sandy loess with roughly vertical joints. 5. Indefinite layer of yellow loess not marked off from 6, containing concretions of iron oxide and a few limestone concretions. 4 Layer of whitish limestone. 3. Yellow sandy loess with rock fragments. 2. Rubble in sandy calcareous matrix. 1. Flaggy shales of C.R. series. A, B, Chipped chert flakes.

and there the fragments are of the same nature as the floor, and they are angular. Two flakes of chert, just like those attributed to human workmanship and found in almost every part of the Colony, were seen in one part of the section, which was carefully examined—a part where a terrace has been cut half-way down, so that one can walk along the middle of the cutting. Near the upper surface of the limestone bands there is always a great number of balls and irregular concretions of brown oxide of iron; these are in the sand, not in the limestone, and they become fewer in numbers upwards. They form an irregular layer, which is continued for a few feet beyond the limestone where the latter thins out, as in Fig. 10. The sand does not contain shells

of any kind, nor bones, so far as my observations went, and the same statement holds goods for the limestone. The limestone occurs in irregularly lenticular layers, and as it is so closely connected with the sand, it is convenient to describe it here instead of under the head of Surface-limestones. It may reach a thickness of 15 feet, but generally it is thinner, and where two layers exist, as in the place represented by Fig. 11, they are separated by a layer of loamy sand containing ferruginous concretions, just like the sand above the limestone. The surface of the limestone is very irregular. It is a whitish rock of variable consistency. Irregularly shaped masses are hard, and have

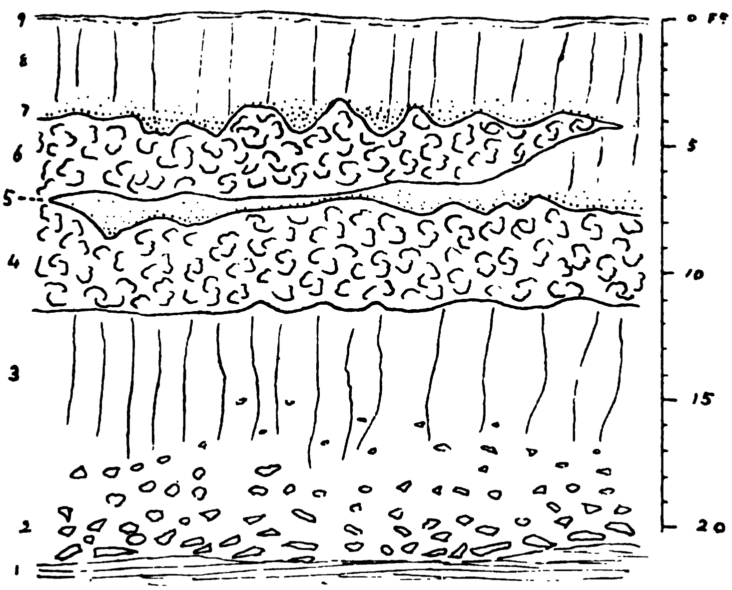


FIG. 11.—Section exposed in water cutting on Put Pan. 9. Surface soil. 8. Yellow sandy loess. 7. Yellow sandy loess with ironstone concretions. 6. Limestone. 5. Yellow sandy loess, with ironstone concretions. 4. Limestone, continuous with 6 on left. 3. Yellow sandy loess. 2. Rubble in sandy calcareous matrix. 1. Flaggy shales of C.R. series.

a concentric structure due to the presence of coats of slightly different tints following the form of the outer surface. These hard masses are embedded in rather softer limestone. The limestone contains sand grains and small angular fragments of shale; these are distributed as the similar fragments are in the sand, viz., they become more numerous downwards towards the rock floor. Immediately overlying the floor the rubble is a collection of angular shale fragments lying in a loose sandy limestone. In parts of the cutting the limestone approaches the surface rather closely, and at places in the veld not far off precisely similar

limestone crops out; this rock differs in no way from the surface-limestone which appears in almost all parts of the Kaap and the Maremane anticline.

The Put Pan cutting gave me the impression that the limestone has been deposited within the sand, and that to a certain extent it pushes aside the constituents of the sand during its deposition. The materials thus pushed aside seem to be chiefly iron oxide and clay, and also much of the sand, but rock fragments larger than 1-10th of an inch or so, and many grains of sand very much smaller than these are included by the limestone.

Near the water-hole there is no limestone, and the sand there is much thinner than elsewhere. The cutting runs north-eastwards towards lower ground, and the surface deposits as a whole become thicker in that direction—in other words, they tend to level up the slope formed by the hard rock below. The limestone does not behave uniformly in the same fashion, its total thickness at any point is not necessarily greater than at another place nearer the water-hole, and it may be altogether absent.

Red sand is abundant on both sides of the Kuruman-Asbestos range; towards the Langeberg the sand becomes paler in colour. To a certain extent the distribution of the red sand is obviously connected with that of the ferruginous rocks of the Griqua Town series, but the Ongeluk beds (Middle Griqua Town) are very often accompanied by sand almost as deeply coloured as that on the Lower Griqua Town beds.

Near the Langebergen the valleys are usually found to be more or less deeply buried under sand, but its depth is difficult to ascertain. It wraps round the north end of the range, and the transverse valleys south of Olifants Hoek are so filled with sand that the mountains rise very steeply from an apparently flat plain from one to four miles wide without definite stream beds traversing them. In nearly all parts of the Langeberg the mountain side rises abruptly from a sandy plain, which abuts against the mountain so as to hide from sight the lowest 300 feet perhaps of the rock slope. This plain slopes very gently towards the nearest valley-line.

In the Koegas Field-Cornetcy there is much sand banked up against hills made of Griqua Town and Matsap beds. On Stink Water there is a ravine showing a section eight feet deep in the red sand; there is enough clay and iron oxide in the sand to give it strength to stand in vertical walls, which are due to a strongly marked jointing; it contains a few small pieces of rock, lava, and jaspers from the neighbouring Griqua Town beds. In the wide sandy country north-east of Piljaars Poort there are sand-hil's which trend south-east, and are slightly concave to the north-east.

On the west side of the Langebergen the country is very sandy; the usual colour is yellowish or light red, but the re-

markable sand hills of Witsands are almost white. These hills occur in an area about eight miles long and five wide; rocks of the Matsap group crop out at the summits of the highest hills and of some of the lower ones; the presence of the Matsap ridges is certainly an important factor in bringing about the accumulation of the sand, which rises to a height of from 100 to 200 feet above the surrounding country. The trend of the main sand hills within the group is N.N.W., and their steepet side is on the E.N.E. The two questions concerning Witsands that are difficult to answer are why the sand gathers in that spot, and why it is so white; the third question, the reason of the occurrence of water in several places, usually excites most interest and wonder, but, as will be pointed out presently, the presence of water is not very difficult to explain.

The accumulation of the sand round the Witsands kopjes has not been explained, and at present the local circumstances are not well enough known to allow the matter to be fairly discussed. The whiteness of the sand is due to the removal of the small amount of iron oxides which give the yellow and red tints to the sand of the surrounding country. In parts of the white sand area the removal of sand by wind has laid bare banks of cellular ironstone just like that found on the Cape Flats and many other parts of the Cape Colony; it differs from the ironstone of the Kuruman hills, etc., in being less compact and in containing no fragments of rock larger than sand grains. It seemed to me that the ferruginous colouring matter from the local sand has accumulated in this cellular ironstone, owing to the long continued action of the water which saturates the lower lying sand in the small area (8 by 5 miles) of Witsands. There were no clear sections which showed how thick the ironstone is or whether it occurs in beds within the sand or in a layer always near the bed-rock, but the exposures favour the view that it is in irregular layers within the sand and at a considerable height above the bed-rock, *i.e.*, that it occurs similarly to the layers of limestone in the Put Pan cutting. The outcrops are quite 18 inches thick, and loosened masses of that size lie near the outcrops.

An accurate survey of the area, combined with precise levelling, would be necessary to decide the cause of a constant supply of water within the sand area. The water is found at a depth of a few feet below the surface on flat places just within the outer groups of sand hills. People told me that it could be got anywhere near the hills, but I do not think that can be the case, for if it were the farmers who live there temporarily or permanently would not go to the trouble of fetching water from spots half a mile from their houses across very heavy sand. From enquiries made from people who have known Witsands for a long time I gathered that the level of the water rises regularly after rain and that it gradually sinks during the drought. After

plentiful rains it stands above the surface in certain of the hollows. Though there seem to be always some hundreds of small stock watered daily at Witsands, as well as a small number of cattle, there never seems to have been a severe strain put upon the water supply. At the time of my visit (October, 1906) the water was 4 feet, 3 feet, and 2 feet below the surface at the three water-holes seen by me; it is fresh.

The quartzites of the Matsap series crop out at several places round the white sand area, and the intervals between the outcrops are covered with sand; the locality gave me the impression that there is either a rock basin or a rock valley dammed up by impervious surface deposits and filled with sand, which becomes saturated with water to a level depending upon the abundance of rain. The sand protects the water from evaporation to a certain extent, and hitherto this water has not been known to be exhausted during the severest drought. The rainfall of this district has not been recorded, but from the appearance of the veld during two rather dry years (1905 and '6), I think it is almost equal to that of the Kuruman district. It has been supposed that the Witsands water comes from a strong spring, but the fact that the water level rises and falls each season shows that some of the water has a more local source. If the underground contours of the sand were such that they would allow rain-water to drain away quickly the water would not rise above the low spots as it does. In several walks to and from the water-holes I could not decide whether they were at a higher or lower level than the flat ground outside; the paths lead over sandy rises and across low ground.

Witsands has long been known as a locality where "lightning-tubes" or "fulgurites" occur.[1] During my visit there I could not find one of them, nor were two natives sent to look for them more successful. I was told that they are got after heavy rain or strong winds, and that they stand more or less vertically out of the sand. Mr. Jooste, of Koodoos Kloof, Hay, kindly gave me three pieces of the tubes, which he had picked up at Witsands. They are rough glass tubes with walls 1-2 mm. thick, with a vitreous surface inside and a dull exterior covered with partly fused sand grains. The walls have collapsed in places, so that the tube is irregularly closed, and the outer side is ridged, owing to the folding in of the wall on each side of a ridge, like the wrinkles on a dried grape. The colour of the tubes is whitish grey. Fragments under the microscope show that the greater part of the wall is made of isotropic glass containing numerous air-bubbles. Partly melted sand grains (of quartz) are abundant. These fulgurites are evidently very like those described from various parts of the world.[1]

[1] R. Marloth, Trans. S.A. Phil. Soc. Minutes of Proceedings, vol. VIII. p. lxx.

(2) *Surface-quartzites and ferruginous rocks.*

On the farms Roodemans Kloof and Paarde Kloof, which lie on the eastern slope of the Langebergen in Hay, there are large patches of a sandstone which passes into quartzites indistinguishable in hand-specimens from the surface-quartzites of the south of Cape Colony.

At Roodemans Kloof the rock forms an area about half a mile long and a quarter wide; it lies on a gentle easterly slope leading to the dry valley which traverses the farm from north to south. The rock is ferruginous in parts, consisting of grains of quartz embedded in a red and brown matrix. The exposed surfaces are often polished, and these portions are made of a very hard rock, consisting of quartz grains and small pieces of quartzite set in a dull siliceous matrix. A thin section of this rock (1660) seen under the microscope shews round and angular quartz grains set in a matrix composed of very small quartz individuals without crystalline boundaries; this quartz is not in crystalline continuity with the quartz grains enclosed by it.[2] No isotropic silica or other substance was seen in the slice. The transition from this very hard rock into a much softer variety, in which the place of the siliceous matrix is taken by earthy matter or by a ferruginous cement, can be seen in almost any part of the outcrops. Although the very hard rock is usually found at the exposed surface and the softer rock below it, the latter also occurs alone over areas of several square yards. These rocks are roughly divided up by vertical joints, and they pass out of sight under the sandy soil which forms the upper part of the slope. The greatest thickness of rock seen at Roodemans Kloof is only two feet; it passes downwards into sandy soil without a sharply defined limit.

On Paarde Kloof the surface-quartzite is exposed along the left side of the steep-banked valley leading south-eastwards from a large kloof in the Langebergen. Its upper surface slopes gradually eastwards and passes under gravelly soil a few yards back from the edge of the bank. It is evidently being cut back by the formation of the lateral valley, and a vertical thickness of 15 feet of the rock has been exposed in the process. The rock as a whole is rather earthy, a loosely consolidated sandstone with

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[1] For descriptions of these glass tubes see Charles Darwin's "Journal of Researches," etc., end of Ch. III. C. D. Gibb, The Geologist, 1859, p. 195, etc. P. Harting, Naturk. verh. d. Koningl. Akad. Deel. XIV. This last paper is illustrated, and the figures might almost have been drawn from Witsands tubes.

[2] This rock corresponds more closely with the "Eingekieselte" rocks of the Northern Kalahari (Botletle beds) described by Passarge and Kalkowski than with the other siliceous surface deposits of the same authors.

Passarge, Die Kalahari, 1904.

Kalkowski, Abh. der naturwiss. Gesellsch. "Isis" in Dresden. Jahrgang, 1901, pp. 55, etc.

irregular tubes and holes filled with sandy earth; the tubes are from a tenth of an inch to one inch in width, and branch in the manner of plant roots. There are irregular layers and patches more or less deeply stained with iron oxides in the usual yellowish-white rock. Pebbles of quartzite and vein quartz, subangular and rounded, occur in thin layers and in small patches; they are usually embedded in a coarser grained matrix than the rest of the sandstone. The rock is not divided up into definite beds, though the occasional layers of gravel and ferruginous material lie nearly horizontally, and give the whole a roughly bedded appearance. At the exposed upper surfaces the sandstone passes into a very hard quartzite, as at Roodemans Kloof. A few yards back from the bank a pit has been sunk, apparently for prospecting purposes, ten feet into the sandstone; the rocks seen here are like those exposed on the bank.

Similar quartzites have not been noticed elsewhere in the district, but the more ferruginous parts of the Roodemans Kloof and Paarde Kloof rock appear to be of just the same nature as the rock formed by the cementation of gravel and soil by iron oxides in many localities in Hay and Kuruman, especially along the flanks of the hills made of the Lower Griqua Town beds.

In almost all the kloofs I examined on the flanks of the Kuruman-Asbestos range there are places where, owing to the removal of the sandy surface soil by water or wind, an irregular surface of hard cemented débris is exposed. This rock is made of angular, subangular, and rounded fragments of local rocks cemented together in a sandy ferruginous matrix. A similar material is often seen on the lower slopes of the hills between the kloofs. Where large fragments are few or altogether absent a hard ferruginous sandstone takes the place of the breccia or conglomerate. In positions such as stream beds where rounded water-worn pebbles usually occur, many of these are found in the matrix, together with angular pieces of rock, but on the lower slopes of the hills outside the kloofs the rock is a breccia.

This ferruginous breccia or conglomerate is especially well exposed near Daniel's Kuil, where it extends for a considerable distance from the hills over the flat ground of the Kaap Plateau; it must then lie on the limestones of the Campbell Rand series. It is seen to be covered by 12 or 18 inches of red sandy soil at the hole which gave to Daniel's Kuil its name (see p. 28). It here contains many pieces of black chert from the Campbell Rand beds, as well as fragments of the Griqua Town beds, and it is about three feet thick.

At Kuruman the ferruginous breccia is found in the village at a distance of five miles from the foot of the hills, and the same is the case at several localities between Kuruman and Griqua Town.

The rock occurs also in the wide valley cut out of the Griqua Town beds behind Khosis Reserve (called Gathlose Reserve in

most of the maps), and at other places on the western side of the Kuruman-Asbestos range, but it does not appear to be so frequently developed on the west as on the east of those hills.

A quite similar rock is formed round all the hills made of the Blink Klip breccia on the Maremane anticline, but the included fragments are here pieces of this breccia.

The ironstone of Witsands has already been described (see p. 72).

Though these ferruginous rocks are probably only seen on the surface where the soil has been removed, there can be little doubt that they underlie the soil over wide areas in the neighbourhood of hills with much iron in them, and in the valleys within the hills, for they are met with in wells sunk in these places.

Although in the case of the Paarde Kloof occurrence the sandstone has been exposed by the cutting back of the valley bank, where the bed of the river is some 30 feet below the top of the bank, and the sandstone is therefore of considerable antiquity if its age be reckoned in years, these rocks, composed of whatever débris there happens to be at each locality, cemented together by iron oxides and silica, are doubtless in process of formation at the present time. The iron oxides and silica must have been taken out of ascending ground water charged with them, just as the carbonate of lime has been taken from such water to form banks of surface limestone, such as those described above from the Put Pan cutting.

There are masses of siliceous material associated with surface limestone in the tufa-covered ground between the Langebergen and the Kuruman hills, and again on England, a farm north of Geluk. These present important differences from the surface quartzites described above, and as but little is yet known about them, they will be briefly described in connection with the limestone in which they occur.

(3) *Gravels.*

Gravels are not developed to an important extent in any part of the district except between the Matsap ridge and the Langebergen, an area described in the last Annual Report (pp. 200, 201). It is possible that this gravel stretches much further than it has been seen, as it may lie under sandy soil north and south of the area mentioned. Some of the kloofs in the Langeberg have well-developed rock terraces, shelves cut by water, at a level of about 20 feet above the bottom of the present streams. On the farm Toto there are patches of gravel lying on such a terrace.

The most interesting gravels seen are those with a calcareous matrix at Mahura Muthla on the Kaap Plateau. Through some prospecting for diamonds they have been well exposed. They

are exposed at a place which is slightly higher (a few feet) than the plateau to the east and west, and they lie some 10 feet above a pan with rocky bottom (of Campbell Rand limestone) immediately to the west. Their extent is unknown, and their mapping out would be a long and difficult work unless many new wells, etc., were being sunk. The exposures seen by me cover an area some 500 yards long by 50 wide, but in parts of it the exposures are small. The surface soil is reddish brown, and contains rough fragments of chert, a few agates, and artificial flakes of chert; this soil is about a foot thick, and is underlain by either a soft whitish limestone or a hard limestone with an irregular lumpy surface. If the limestone is hard it becomes softer below. The limestone contains well-worn small pebbles of agate, chert, and red jasper; at places these pebbles are very abundant, elsewhere they occur sparingly. At one place the depth of the soil and limestone is only 18-24 inches, and the underlying Campbell Rand limestone is exposed over an area of some 200 square yards, the soil and surface gravelly limestone having been stripped off by the prospectors. The blue dolomitic limestone is bedded horizontally, and presents a curiously pitted surface, owing to the presence of many irregularly circular depressions from one to two feet deep, evidently formed or at least enlarged by solution. In a different situation some of these depressions might have passed as potholes. In another part of the workings the bed-rock is reached at 8 feet, the overlying material being limestone, with round pebbles, very hard on the top and soft below. Another pit is down 12 feet in the pebbly limestone without exposing the bed-rock. Artificially chipped cherts occurs in the limestone near the surface, but I did not find these worked stones in such a position that they undoubtedly belonged to the gravel, and were contemporaneous with it. In addition to the small pebbles, there are larger rounded pieces of rock, including blue limestone from the Campbell Rand beds, chert from the same formation, grey and reddish quartzites that may have come from the Black Reef series, diabase from the Pniel group, and red jasper. Only one piece of rock which probably came from the Karroo beds was seen by me, a 3-inch pebble of silicified wood like that from the Ecca and Beaufort beds; Mr. Fenwick Stow, who was concerned in the prospecting, told me he had seen several of these during the washing of the gravel. In one part of the workings there is iron-stone gravel under the soil in place of the calcareous rock. In several places there are gravels with little or no limestone in the matrix lying below the usual limestone.

The agates, which form by far the greater number of pebbles in these gravels, are precisely like those in the river-diggings along the Vaal, and they doubtless came from the Pniel lavas. There is an inlier of these lavas near Takwanen, and they crop out round the edge of the plateau, usually at a lower level than

the surface of the plateau, though on the north edge they probably lie in places above that level, *e.g.*, at Massouw's Kop, and in former times they may have done so over a wider area than now. In the Takwanen inlier, however, we have the levelled-off remains of a ridge partly made of the Pniel lavas, and it is quite possible that the agates came from this source, which is some 30 miles north-east of the gravel pits. Further work may reveal the presence of a nearer inlier. The source of the fossil wood cannot yet be decided; it is the only direct evidence yet found of the former presence of Karroo beds on the Kaap Plateau. No granite or schists were seen in the gravels, nor were any shells noticed in the limestone associated with them.

In the Langeberg region there is often a considerable depth of coarse rubble in the kloofs quite near their steeply-graded tract. Where the kloofs are very steep the solid rocks crop out all the way along the bed, but where the grade becomes less, though before one reaches the almost flat ground, there is much rubble, made of angular fragments of the Matsap quartzite and sand. At Mount Temple there is a water cutting about 30 feet deep; the uppermost 20 feet of material is coarse rubble, in which the blocks are as much as 15 inches across; below this there is sandy débris, with very little clay in it. The cutting does not reach the solid rock.

Similar sections, though without such a definite lower layer of sand without rubble, were seen at several farms along the eastern side of the range.

(4) *Limestones and associated siliceous rocks.*

The surface-limestones can be roughly divided into two classes, those which occur in patches, either at intervals or so thickly that they almost form wide connected areas, and those in large areas, either narrow and occupying the floors of valleys or of great extent.

The first class of limestone is found overlying rock containing carbonate of lime or lime-silicates, which produce carbonate of lime on weathering. The chief rock formation on which this kind of surface-limestone is formed in this district is, of course, the Campbell Rand series. Almost everywhere on the Kaap Plateau and the Maremane anticline patches of surface-limestone are seen separating the rough outcrops of the underlying formation or covering it entirely. In the sandy country a layer of tufaceous limestone is usually found in a well or other cutting through the sand. The depth below the surface of the sand at which the limestone is first seen varies in the exposures I saw up to 10 feet, and the thickness of the calc-tufa varies indefinitely. Under the sand on the Kathu Reserve it is more than 15 feet thick, but the underlying rock is not exposed there, and

its nature is therefore uncertain, though it probably belongs to the Campbell Rand group. The limestone is very hard, as a rule, at the surface and to a depth of two or three inches from it, but further from the surface it is generally softer. It includes sand, pebbles, and any earthy matter that may happen to be present. At Mahura Muthla on the Kaap there is a gravel cemented together with white limestone. The pebbles in this case are of agate, and other rocks which do not occur in the immdiate neighbourhood, and the gravels have been prospected for diamonds. The exposures thus made show that the thickness of the limestone varies up to twelve feet within 100 yards, and that in places it is hard throughout. It may rest directly on the Campbell Rand limestone or a bed of loose gravel may lie between the two limestones. These surface-limestones were formed by the deposition of lime from water which evaporated at or near the surface. The water doubtless got the lime from the underlying rock. In places where a continuous supply of water is maintained, as in spots which are always damp, owing to the presence of a weak spring, the deposit of limestone takes place rapidly. A remarkable instance of this was shown me by Mr. Cawood, of Orange Grove (below the escarpment and between Baviaans Krantz and Schmidt's Drift). He opened up a damp spot and found the drill and pick marks, made by the first owner of the farm some 27 years previously, at a depth of 3 feet below the surface of the tufa. This is probably an extreme case, but similar deposition must be in progress at many places along the escarpment where water is constantly oozing from the rock. In an open flat, such as the Kaap Plateau, the deposition is brought about by the ascending water after rain has saturated the ground and when the latter dries out. A description of the limestone exposed in the Put Pan water cutting is given on p. 68, and it is probably typical of a very wide area.

The shape of the limestone masses may be very irregular. Near Gamopedi, on the left bank of the Kuruman River, the limestone occasionally projects above the red sand flanking the Kuruman hills. At one spot large masses of this rock had been taken out from a pit, which, however, is now mostly filled with sand, so that the rock *in situ* is not well exposed. The loose blocks show that the limestone may be two feet thick, and some of it has a curious appearance, owing to the presence of more or less tubular holes up to two inches in diameter going through the rock in various directions. These are filled with red sand, except near the surfaces, where the sand can fall out, and by the gradual growth of the limestone small pockets of sand must be completely enclosed; by the deposition of limestone in these enclosures there will be produced a patch of very sandy limestone, just like certain sandy lumps sometimes seen in the limestone. Otherwise the deposition of the lime appears to force aside a considerable amount of sand, and only to include a small

part of that which once occupied the space now filled chiefly with limestone.

Though surface-limestone is more abundant on the dolomite areas than elsewhere, it is not confined to them. The Lower Griqua Town beds have very little limestone on them where they are not in the neighbourhood of a valley draining a dolomite country. The Matsap Flats, for instance, are covered with much limestone lying on the Lower Griqua Town beds, but an old valley bottom draining the southern part of the Maremane anticline traverses the plain on its western side, and the rest of the plain has probably at times been crossed by the old river; so formerly, even if it is not the case at present, the subsoil must have been saturated with water containing carbonate of lime in solution. Following the Lower Griqua Town beds southwards towards the Stink Water boundary, we find very little limestone either exposed at the surface or in wells. Near the top of the Lower Griqua Town beds, however, calcareous rocks are again found, though the carbonates are present in comparatively small quantities, and in places surface-limestone of local origin again appears. Such is the case at Dunmore, south of the great Ongeluk-Witwater syncline, where 15 feet of loose white limestone have been exposed in a pit.

On the Ongeluk volcanic rocks (Middle Griqua Town) surface-limestone is in places developed in considerable quantity, especially where the ground is flat, as in the northern part of the Ongeluk-Witwater syncline. The lavas very probably yield enough lime on weathering to account for the surface-limestone seen.

No limestone worth mentioning has been found on the Upper Griqua Town beds south of the Bechuanaland fence, nor on the Matsap beds, except where they are traversed by valleys coming from a limestone area, such as the Matsap "loop" south of Bakens Kop. The Upper Griqua Town beds contain a few thin beds of dolomitic limestone, but no calcareous rocks have been noticed in the Matsap beds, excepting some of the lavas which contain calcite as an alteration product. These lavas do not cover a wide area at the surface, and they either form hilly ground unfavourable for the accumulation of limestone or are deeply buried under sand.

The second class of superficial calcareous rocks, those which cover a wide area continuously, are very probably closely connected with certain of the first class, but their separation is not convenient until more is known about them.

The tufa which fills or nearly fills old valleys draining dolomite areas requires no special explanation. It was referred to in the last Annual Report in connection with the Matsap valley. The valley which drains the northern part of the Maremane anticline is also largely filled with tufa down to its junction with the

Kuruman River below Tsenin. No outcrops of the underlying rock were seen below Gamagara, and the country on the right bank is covered with sand, through which surface-limestone crops out over a very large area. In a traverse from the north end of the Langeberg to Gamopedi, on a line sixty miles long, the underlying rock was only found once, on Alister, till the foot-hills of the Kuruman range were reached. A large part of this wide area is covered with surface-limestone, though it is very improbable that the Campbell Rand series directly underlies the superficial deposit. It is difficult to decide how much of this limestone is derived from the water coming down the valley, but it seems to me at present not unlikely that the whole of it was so derived. The area is flat, and but slightly above the valley floor (at most 100 feet). On the farm Flatlands, east of the valley bottom, there are two wells being sunk in the limestone, 50 feet and 40 feet deep respectively. In neither case has the bedrock been struck. The material thrown from these wells is interesting, though, as at the time of my visit there was no one there, I could not go down to see the section, and consequently I am ignorant of the depth from which certain rocks came. There is softer rock at the surface and within two or three feet of it than that which comes from greater depths. A band of limestone with subangular fragments of banded jaspers and volcanic rocks, all from the Griqua Town beds, was passed through in the western of the two wells, but at what depth I do not know. A red earthy rock occurs with the limestone, and is similar to the red material thrown out from wells between the valley and the Langeberg; it contains small crystals of calcite. The most interesting fact about the limestones on Flatlands is the occurrence of opaline silica and chalcedony in irregularly disposed veins and cavities in the limestone, and also as a cement in masses with irregular shape. Parts of the siliceous material are as clear as glass, and are quite isotropic; this material seems to be the same as hyalite. Other parts, also isotropic, have a delicate blue colour. The bulk of the silica, however, seems to be in the form of chalcedony, for it is doubly refractive, and shows the usual appearance of agate under the miscroscope. Thin sections of these rocks have not yet been cut, but the siliceous portions were examined in the form of powder and chips.

No shells of molluscs or other organic remains have been found in the limestone, but one mass of opaline silica looks as if it might have been formed in the place of a shell such as *Unio*, but this is uncertain.

On the farm England, about eight miles north of Geluk, and lying at the head of the Mashowing valley, there is a considerable amount of surface-limestone overlying granite and gneiss. In one well it is 15 feet thick. From the well at Mr. Cullinan's garden there comes a siliceous rock forming irregular flattish masses in the limestone; this rock is like some of those men-

tioned above from Flatlands. From a hole some half-mile from Mr. Cullinan's house there were thrown large masses of siliceous rock, brittle as glass, in which no recognisable detrital fragments are seen. It is made of opaline silica and chalcedony. Its relations to the sand at the surface are not well exposed, though it appeared to lie under about three feet of reddish sand. Some masses of ironstone, made of hydrated iron oxide and rock fragments and containing chips of the opaline rock, occur, overlain by sand, in the immediate neighbourhood.

Calcareous tufa is not abundant in the Mashowing valley near Motiton. An occurrence at the Klein Chwaing pan will be mentioned later.

X. PANS.

The variously shaped shallow depressions called pans are rather numerous in the district under consideration. They vary in size from a few yards to more than a mile in diameter. In shape they are usually circular, but many oval and a few quite irregularly shaped pans have been seen. Many of them are probably hollows in the solid rock, perhaps only a few feet—less than ten—deep, but this fact is not easy to prove, for there is always some sandy or tufaceous material round the pan, and there are not often sufficient exposures of rock to prove its continuity at a higher level than the floor all round the pan.

It will be convenient to describe briefly one or more pans from each formation on which they lie.

On the granite area only one pan of any importance was seen; it is on the farm Zoutpan, and quite close to Klein Chwaing Reserve, which takes its name from the pan. Though the farm is called Zoutpan, I was told that salt is not collected from the pan; the surface is brak and the water, when present, is too brak for animals to drink, but the salt is not in large enough quantities to collect. The pan is nearly circular and about 1,000 yards in diameter; formerly it was wider in the north-south direction, for there is a flat grassy surface about 800 yards long directly south of the pan a few inches above the surface of the pan itself. The floor of the pan generally is a grey gritty and sandy mud, with salt crystals and some gypsum in it. There are four outcrops of gneissose granite in the pan rising about two feet above its surface. To the north there is a grassy slope rising to a height of about 100 feet above the pan; the soil is sandy, with some tufaceous limestone, and the nearest granite seen is about a mile away. To the east the granite is exposed in water-holes; it lies under a grey soil and loose earthy limestone. The granite in these holes lies some 20 feet or more above the pan. To the west similar sections are seen, and that represented in Fig. 12 was taken from one of the western water-holes. The soft limestone is earthy, and contains shells of

Physa; it is traversed by more or less vertical tubular holes. The gneiss at the base of the section lies some 15 feet above the pan floor. Towards the south the ground rises gradually from the grassy flat south of the pan, and at a dry well about three miles to the south granite is seen in places considerably above the level of the pan. There are small ridges of yellow blown sand round the south end of the pan. The water from the holes east and west of the pan is fresh.

The few other pans seen on the granite north-north-east of Klein Chwaing are under 100 yards in diameter, and are bare places where the granite is exposed at the surface; they are less than 10 feet below the surrounding ground, which has a sandy soil derived from the granite.

No pans were seen on the small ridge made by the Kraaipan formation on Kameel Rand and Hamburg.

A pan on the Pniel lavas lies just south of the Kraaipan ridge.

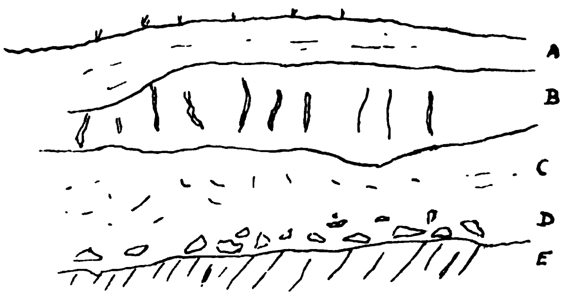

FIG. 12.—Section in water hole on the west side of the Klein Chwaing Pan. A, Soil with fragments of limestone and quartz. B, 18 to 24 inches of loose limestone with Physa shells. C. About 18 inches of loose soil and limestone. D, Rubble of gneiss fragments. E, Gneiss.

It is under 200 yards in diameter; the soil is a thin grey-brown mud and there are numerous outcrops of the lavas on the pan floor. The surrounding ground is a red sandy soil on the north towards the Kraaipan formation and a grey soil on the other sides, underlain presumably by lava. There is a large ill-defined grassy pan on Morgenzon lying on the lavas which make a few outcrops where a road has cut through the thin soil. Another pan on the same formation is found on Schiet Fontein, also with a few outcrops of amygdaloid. Small pans, in all of which the rock is exposed at places, were seen on the blue lavas of England and Harbro. On Kaffir Pan the only pan seen lies on the acid lavas of the Zoetlief beds, exposed in low rounded surfaces on the floor. A small pan lies on the Black Reef beds of Schildpad Kuil; the soil is thin, but the Black Reef beds do not crop out on the floor. The large pan on Mooi Fontein lies on the boundary between the Black Reef and Campbell Rand series; the former is seen in a cutting on the north margin of the pan,

and crops out in a few places near that edge; the limestones of the Campbell Rand group crop out on the western extension of the pan, which is elongated in the direction of the strike of the beds. Another pan in a similar position was seen on New York. Towards Geluk there are several ill-defined pans on the same horizon. Most of these are grass-covered, but the Mooi Fontein pan has a brak calcareous mud floor.

By far the greater number of pans seen lay on the Campbell Rand limestone of the Kaap Plateau and the Maremane anticline. In many cases these are more or less circular patches, in which the limestone crops out abundantly, usually with more or less hard tufa lying between and partly covering the outcrops. They are only a few feet below the country round them. The large Rooi Pan near Daniels Kuil is a wide grassy depression in the upper part of the dry river which traverses the Plateau south-east of Daniel's Kuil. On A 58 a well has been sunk just outside the depression through 20 feet of loose calcareous rock, a surface-limestone. The top of the well is about 15 feet above the floor of the depression. The Rooi Pan is only a wide valley partially filled in with calcareous tufa and sand. Parts of it are rather lower than others, owing to the irregular accumulation of the surface deposits, and after heavy rain water stands for a few hours in various places.

Between Kuruman and Taungs several pans with white calc-tufa on their floors were seen. Usually the tufaceous limestone is rather soft, but in some cases the surface is hard in irregular patches, and the softer material lies between the hard outcrops.

On the area occupied by the Griqua Town series pans are not very abundant. Those on the Lower group are always small. The Middle group (Ongeluk lavas) has more pans on it; on the north end of the Ongeluk-Witwater syncline, where there are wide flats on the lavas or on diabasic rocks intruded amongst those lavas, there are many wide pans covered with grass, especially on Vogelstruis Fontein and between that farm and Groen Water. Several shallow prospecting pits were sunk on that area during 1906, and they all showed calcareous tufa overlying decomposed diabasic rock. West of the Kuruman hills there are pans on the Ongeluk lavas, and many were seen on the same group in the country between the Paling fault and the Langebergen. In these pans the underlying rock was never seen in outcrops, though wells in some cases showed that it lies near the surface. The floor of these pans is either a sandy mud or tufa with a considerable amount of clayey matter in it. The Ongeluk lavas and the intrusive rocks associated with them appear to decompose more uniformly in such situations than the granite, Pniel and Zoetlief lavas, and the Campbell Rand beds. The pans on the Ongeluk beds west of the Paling fault and near the Kuruman hills are evidently slight hollows in the solid rock,

for the lavas crop out near them on all sides. There are but few pans on the area occupied by the Matsap series, and those that do occur are in valleys between rather high ridges, where there is a considerable accumulation of surface deposits. In one such pan east of Dunmurray a well has been sunk through some ten feet of sandy material into quartzites. No quartzite outcrops were seen in any of these pans, which are small and of slight depth.

In the large tracts of country on the Kaap Plateau covered with thick reddish sand pans are rarely seen, and the same is the case in the surface-limestone area south and east of the Gamagara valley; in one small pan seen in the latter area and referred to on a previous page a well has been sunk 40 feet into the limestone without exposing the underlying rock.

GEOLOGICAL SURVEY

OF THE

EASTERN PORTION OF GRIQUALAND WEST.

BY

ALEX. L. DU TOIT.

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INTRODUCTORY.

The area mapped extends from a point a little north of Taungs as far southwards as the Orange River, and is bounded on the east by the Transvaal and the Orange River Colony, and on the west by the Kaap Plateau. It covers an area of a little over 6,000 square miles, and includes the whole of the Division of Kimberley, the greater part of Herbert and Barkly West, and the southern portion of Vryburg.

Topographical Features.—The channel of the Orange River is shallow in depth at Hopetown, but rapidly deepens, until the river is hemmed in by walls of diabase, several hundred feet in height. From a point a little above Mark's Drift to its confluence with the Vaal River, the gradient is flatter, and the banks are low and sandy. The country along the Vaal is more diversified, there being high ridges at Douglas and to the north of Schmidt's Drift.

The Harts River winds about in a broad shallow valley, and has an extremely low gradient. To the west a gentle slope, broken by occasional ridges, leads up to the base of the escarpment of the Kaap Plateau.

The altitude of the edge of the escarpment does not vary appreciably from 4,000 feet above sea-level between Vryburg and Campbell; from the edge the plateau rises gently, but continuously towards the north-west.

To the east of Taungs there is a similar plateau, with almost the same altitude. This is continued southwards as a gentle ridge, and forms the watershed between the Harts and Vaal Rivers. A most unique feature about the Harts River is that in its upper reaches its channel is several hundred feet below the bed of the Vaal at Warrenton. Such a case, in which a tributary stream flows for some distance at a lower level than the main stream, is most unusual.

The eastern portion of this area consists of broad sandy flats, dotted with flat-topped dolerite-capped hills. The highest point is Kols Kop, near Enslin Siding (4,486 feet).

The Geological Formations.—With the exception of brief notes upon the geology in the neighbourhood of Kimberley and the "Diggings" by Chaper, Cohen, Moulle, Bauer, Stow, De Launay, Gardner Williams, and Coe, and excluding the description of the Diamond pipes, the only detailed account of any

part of this area is that by G. W. Stow,* dealing with a strip of country extending from the Modder River to Douglas and Campbell.

A report by Stow describing the area between Kimberley and Douglas remains in manuscript in the library of the Geological Society at Johannesburg. To this I have had no access however.

Stow's paper suffers from the mass of insignificant detail with which it is overburdened; moreover, he confounded the Karroo dolerites with the Pniel lavas, and imagined that there was a definite and regularly ascending succession of Karroo strata from west to east. He does not seem to have completely understood the nature of the Dwyka conglomerate and boulder-shales, or realised the rapid variation in character and altitude which they show. Since he gave the first connected account of the geology of Griqualand West, several of Stow's names have been retained. It would be well if the term "Backhouse conglomerate," however, dropped out of use.

The geological formations may be arranged as below, in descending order:—

Karroo System.	Ecca series:—shales. Dwyka series:—"white band," upper shales, boulder-beds.
Transvaal System.	Campbell Rand series:—dolomites, limestones, cherts, and shales. Black Reef series:—quartzites and flagstones.
Ventersdorp System.	Pniel series:—volcanics, quartzites, and conglomerates. Zoetlief series:—rhyolites and conglomerates.
	Granite and gneiss.

The wavy line indicates an unconformity.

In addition, we have numerous basic intrusions, both of pre- and post-Karroo age, the extremely numerous kimberlite (blue ground) pipes and fissures, and the superficial deposits, including the diamondiferous gravels of the Vaal River.

The diamond-bearing formations will be treated of separately in Sections II. and III.

I must here take the opportunity of acknowledging the assistance which I have been afforded by the Manager of the De Beers Company and the various officials connected with that Institution, among whom Mr. Addams, Chief Mine Surveyor, must be specially mentioned. To the managers of the outside mines, I am also indebted both for information and for specimens.

* G. W. Stow. Quart. Journ. Geol. Soc. Vol. XXX, p. 581, 1873.

SECTION I.—GENERAL GEOLOGY.

I. THE GRANITE.

Although there can be but little doubt that the granite extends continuously below ground from the division of Mafeking into that of Prieska, there are only a few places, and these some distance apart, where the overlying formations have been sufficiently denuded away to reveal it.

In addition, we have the sections afforded by the De Beers Mine, where the granite has been penetrated by the main shaft at a depth of 2,136 feet, and by the Kimberley Mine, where it has been struck at 2,702 feet, and proved to the depth of nearly 3,000 feet below the surface.

On Modimoe, nine miles to the north-east of Taungs, a gentle anticline, striking north and south, and pitching towards the Harts River, brings up the granite from below the diabase. The rock is a grey or slightly pinkish medium-grained muscovite granite, possessing in places a feebly-developed foliation. It is traversed by a few pegmatites and by quartz veins.

Nowhere else is this formation seen in the district of Taungs, but Dr. E. Jorissen informs me that an inlier of granite occurs on Fourie's Graf (Transvaal), in the Pudimoe valley, a little to the north-west of Modimoe. Further up the Harts River, in Bloemhof,* granite covers a wide area.

The granite in the De Beers Mine is a well-foliated, hornblendic variety, practically a gneiss, with foliation planes striking about north and south. The rock is seamed in all directions by veins of pegmatite, carrying pink felspar and either muscovite or biotite mica. Another variety of granite from the mine carries instead of hornblende a little greenish biotite, which is intergrown with epidote, the latter being a primary constituent. The rock in the Kimberley Mine is a grey biotite-gneiss.

The next occurrence of granite is on the left bank of the Riet River, at a point about a mile and a half from the Orange River Colony boundary; the outcrops only cover a small area. The granite is, as a rule, a fine-grained gneissic variety, containing biotite-mica, and having narrow aplitic bands. The foliation planes strike north-westwards.

By the denudation of an anticline in the Ventersdorp system on the north bank of the Orange River between Douglas and Hopetown, a core of granite has been revealed. Outcrops are infrequent, owing to the amount of Dwyka in the valley, as well as to the thick sandy soil.

* G. G. Holmes, The Geology of the South-Western Transvaal. Trans. Geol. Soc. S. A., Vol. IX, p. 95, 1906.

On the farm Ettrick and close to the homestead is a patch of medium-grained foliated biotite granite, sometimes carrying muscovite mica in addition. The foliation planes strike north-north-eastwards. To the south are two little hummocks of granite, surrounded by Dwyka conglomerate.

On the north side of Summerhill granite appears below the Pniel quartzites, the latter dipping towards the east at a low angle.

The rock is a highly-foliated muscovite gneiss, with both fine and coarse grained bands, traversed by quartz veins. The foliation planes strike about north and south.

The last granite outcrop, and the most remarkable for several reasons, forms a small mound on the farm Donnybrook, a little to the east of the railway at a point several miles north of the Orange River. It is about 50 yards long by 30 broad, and rises from a flat of Dwyka shales. Although the shales abut directly against the granite without any glacial conglomerate intervening, there can be no doubt that the mass is a glaciated hummock, while it is the furthermost exposure yet known of the old Karroo floor up the valley of the Orange River. An odd feature in connection with this little dome-shaped mass of granite is the fact that a thin sheet of Karroo dolerite has been intruded along the junction with the overlying shales, and has also severed the crown of the dome from the rest of the mass. A little prospecting shaft shows, beginning from the bottom, two feet of coarse dolerite, with a tachylitic fine-grained selvage at the junction with the granite. The latter is three feet thick, with foliation planes dipping at a very high angle. Above comes the base of another sheet of dolerite, and for a distance of about a foot there is a transition zone between the acid and the basic rock. The surface of the granite exposure has numerous little patches of dolerite adhering to it or penetrating between the joints.

Wherever the granite is fresh and hard, the junction with the dolerite is either sharp or the transition takes place within a distance of about half an inch. Along the original surface of the hummock, where the rock had been weathered and shattered during its glaciation in Dwyka times, there has been a great amount of incorporation, producing a belt of brownish grey coloured rock up to eighteen inches in thickness. The basic magma has permeated the friable granite and partly dissolved the fragments, producing a mixed rock, which is frequently brecciated, and has a kind of gneissic structure.

The granite is a fine-grained, light-coloured variety, with foliation planes striking north-north-east. Here and there it is somewhat porphyritic.

II. THE VENTERSDORP SYSTEM.

In the area to the north, described in last year's Report, this formation was divided into a lower and an upper group, separated from one another by an unconformity. To the lower one, consisting mainly of acid volcanics, the term Zoetlief Beds was given, while the upper one, composed of basic lavas and breccias, quartzites, and conglomerates, was termed simply the Diabase Formation.

Both divisions occur in the area now described, and the latter group is seen to correspond to the *Pniel Volcanic series* of Stow.*

A. The Zoetlief Beds.

The quartz-porphyries (rhyolites) proved in the workings of the Kimberley and De Beers Mines and cropping out on the Riet River correspond to the Zoetlief beds of the Vryburg Division. The succession at Kimberley is so closely paralleled by that on the Riet River that it will be well to commence with the description of the latter area.

As shown on the map (Fig. 1), the rhyolites occur west of the railway, in a series of detached outcrops extending from Klokfontein Siding across the Riet River. The majority of these are little hummocks surrounded by the Dwyka formation, a proof of the very uneven floor upon which the latter rests. The Klokfontein rhyolite was observed by Stow,† but was mistaken by him for a quartzite.

The rhyolites have rather constant lithological characters; they are lavas with a stony base in which are set small blebs of quartz, while phenocrysts of orthoclase felspar are not prominent. Boulders of this material when occurring in the Dwyka conglomerate to the south-west can without hesitation be distinguished from the numerous quartz-porphyry erratics from other sources. A most striking feature of the rhyolites is the fine fluxion structure which they exhibit. On Witkop Laagte the planes of flow dip evenly at an angle of about 20° towards the south-west, but in all other outcrops the structures become complex and the fluxion-planes are contorted, sharply folded, and often knotted. Surfaces of sliding are numerous, showing parallel striping and grooving owing to the presence in the moving material during its plastic condition of hard quartz blebs. Some of the lavas have such a well-developed fissility that they can be cleaved to form flagstones.

That the structures described are not due to earth-movement is shown by the absence, as a rule, of any constancy of dip or strike even for a few yards.

* G. W. Stow, Quart. Journ. Geol. Soc., Vol. XXX, p. 581, plate 35, 1873.
† *Loc. cit.* p. 584.

Brecciated rock occurs only now and then; one outcrop was observed along the railway at $619\frac{3}{4}$ miles, where the rhyolites pass into a marvellously tough fine-grained breccia. The exposure is entirely surrounded by dolerite. Amygdaloidal and compact varieties are scarcely represented.

Relation to the Pniel Series.—The relation to the granite inlier on Klipdrift is not seen, but the contacts with the overlying diabases are exposed at several points. Along the Riet River

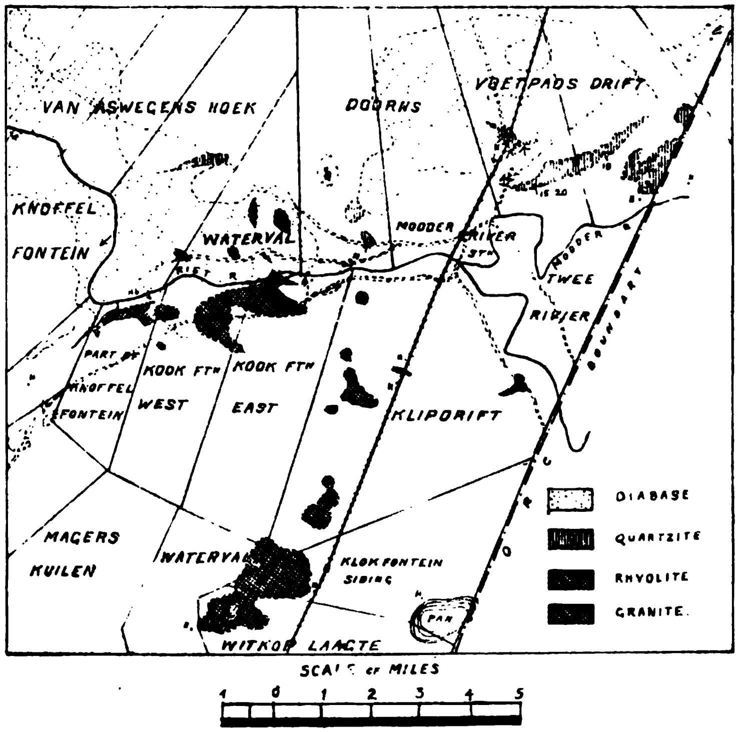

FIG. 1.—Geological Map of the area at the junction of the Modder and Riet Rivers. The unshaded portions are occupied by Karroo and recent deposits.

and to the north the rhyolites form low hummocks surrounded by diabase. Their position precludes the possibility of their being inliers due to folding only, inasmuch as the overlying diabases have low dips.

The uncomfortable nature of the junction is further borne out by the fine sections in the gorge of the Riet River at the south-eastern corner of Waterval. The surface of the rhyolite forms abrupt ridges and hollows, over which the diabase has flowed, the inclination of the contacts being as high as 45°. The banding in the rhyolite due to fluxion is nearly parallel to the ridges

(west-north-west), and more or less vertical, and has doubtless been a factor in their formation. Different beds of diabase are brought in turn into contact with the vertically banded lavas, and the material at the contact often contains angular fragments of rhyolite.

That the rhyolite extends below the diabase in a northerly direction for some distance, perhaps continuously to Kimberley, is indicated by the presence of boulders of that rock as inclusions in the " yellow-ground " of a pipe at Wimbledon Station. These inclusions differ lithologically from the quartz-porphyry so abundant in the Dwyka conglomerate, and cannot, therefore, have been derived from that formation.

Kimberley Area.—In the De Beers mine the granite has been proved at a depth of about 1,900 feet in a winze close to the edge of the pipe (Fig 2). From this point the granite-rhyolite junction falls towards the north-west and dips below the 2,040-foot level a short distance from the main shaft. The granite surface then becomes steeply inclined, and though the base of the rhyolites is reached in the shaft at 2,075 feet, the granite is only cut at the depth of 2,137 feet, the intervening strata consisting of coarse green quartzites and a basal conglomerate several feet in thickness.

The sedimentary rocks are not seen in the 2,040 level, and the whole formation must abut unconformably and thin out against a slope of granite. From the De Beers mine the beds slope towards the Kimberley mine, and increase in thickness. The 61 feet of sediments have thickened to 106 feet at the edge of the Kimberley mine. From this point they continue to slope towards the main shaft, and then become nearly horizontal. The section in the shaft is as follows:—Quartzites, 62 feet; rhyolite, 141 feet; quartzites and flagstones, 110 feet; and conglomerates, 106 feet. Since the flow of rhyolite is absent both in De Beers and at the edge of the Kimberley mine, it must thin out and disappear within a distance of a quarter of a mile, and must therefore be a wedge-shaped intercalation.

The flagstones are very micaceous and fissile, and are finely ripple-marked; the quartzite is a hard, gritty, green variety, which contains pebbles and passes into a conglomerate. The inclusions are well rounded, and may attain a diameter of a foot. They consist of quartz, white or pale-greenish quartzites, striped quartzite, and granite and gneiss, chiefly muscovite varieties. The matrix is a green quartzite, containing a certain amount of carbonate in veins and patches; it is intensely hard, and it is impossible to obtain unbroken pebbles from it. The base of the conglomerate has been reached at the depth of 2,702 feet in No. 9 Prospect Shaft, so it is clear that the granite surface must have a considerable inclination between the two mines.

In the Eighteenth Annual Report of the De Beers Consolidated Mines (1906), from which I have obtained much informa-

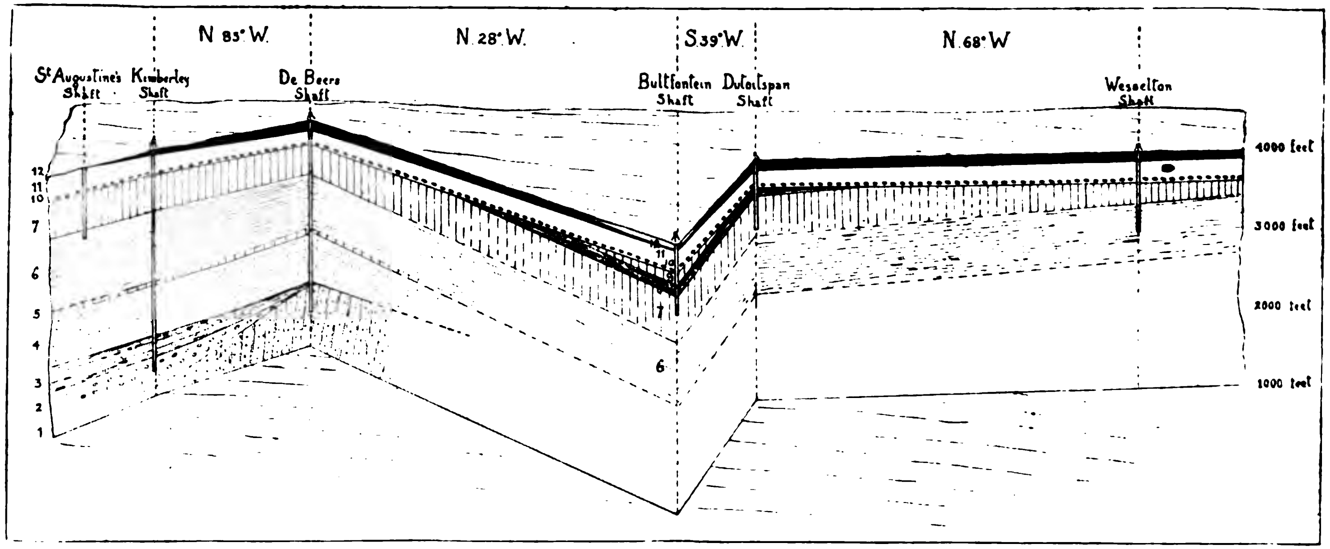

FIG. 2.—Sectional elevation through the Kimberley group of mines, taken from the south. 1, gneissic granite; 2, conglomerate; 3, quartzites with an interbedded rhyolite flow; 4, rhyolite (quartz-porphyry); 5, diabase; 6, quartzites; 7, diabase and amygdaloid; 8, quartzites; 9, diabase; 10, Dwyka conglomerate; 11, Dwyka shales; 12, dolerite.

tion, the conglomerate has been called the Vaal River Conglomerate, since it is regarded as the lowest member of the Vaal River or Ventersdorp system. The naming is not a matter of much importance, but I think that the term Kimberley Conglomerate may perhaps be preferable.

The sedimentaries underlying and intercalated with the rhyolites have, as their composition indicates, been derived by the denudation of an area of granite and quartzite. This probably lay somewhere toward the east.

The thickness of the volcanic rocks is 762 feet in the Kimberley main shaft, and 868 feet at the edge of the pipe; the total thickness of the whole formation must exceed 1,300 feet.

The volcanic rock consists mainly of a massive pale-green quartz-porphyry or rhyolite. Amygdaloidal and felsitic varieties are also present, and there is every transition from compact to highly amygdaloidal or pumiceous types, while acid brecciated lavas and tuffs are also, though not abundantly, represented. Vesicular varieties are more abundant toward the upper limit of the volcanics—for example, in De Beers Mine, between 1,440 and 1,500 feet.

A petrographical description of some of these rocks has been given by Mr. Rastall,* and to this there is little to add. Thin slices of the rhyolites prove them to be almost identical with the quartz-porphyries of the Zoetlief beds of Vryburg. They show the same corrosion of the quartz-phenocrysts, the pseudomorphs after enstatite, the alteration of the felspar, and an extensive silicification of the whole rock.

Some specimens from De Beers at 1,400 feet and the Kimberley mine at 2,160 feet are orthoclase-porphyries, while a rock from the 1,400 foot level of the former, practically at the junction with the Pniel diabase, is an extremely fine-grained chert.

The relation of the Pniel series to the acid volcanics, as shown by the mine sections, will be considered later. (p. 98).

B. The Pniel Series.

The term "Pniel Rocks" was employed by Stow in 1873 in his description of the amygdaloidal and associated rocks of the Vaal River valley. The volcanic rocks contain interbedded quartzites and conglomerates, which, though not often exposed, constitute no small proportion of the total thickness of the formation.

These beds are exposed east of the Harts-Vaal River, wherever the covering of the Dwyka series has been denuded away, and they form all the high ground along the Vaal River.

* R. H. Rastall. Rept. South African Assoc., Adv. Sci. for 1906, p. 275, 1907.

Owing to the isolated nature of many of the outcrops and to the difficulty with which the bedding planes in the lavas are recognised, it is neither easy to make out the exact succession nor to estimate the thickness of the formation.

The following may be considered to represent roughly the succession, though this is subject to variation in different areas:—

3. Zone of porphyritic lavas: diabase, porphyritic diabase, quartz-porphyry, and quartzite.
2. Zone of normal diabases.
1. Zone of quartzites and conglomerates, with diabase intercalations.

Tuffs, breccias, and brecciated lavas occur in all three zones.

Commencing the description with an account of the development in the Kimberley mines, we find that the surface of the rhyolite undulates, and has no constant direction of slope; there is a fall of 190 feet between the De Beers and the Kimberley shafts. The main quartzite does not rest directly upon the rhyolite, but is separated from it by a bed of diabase, varying in thickness from 72 to 50 feet, the thinning taking place in a southerly direction.

The very lowest layer of the quartzite (at 1,528 feet in the shaft of the Kimberley Mine) is practically a conglomerate, and is crowded with pebbles of quartz-porphyry, granite and quartzite, and fragments of quartz and hard black slate. Inclusions of diabase are absent, and the presence of quartz-porphyry indicates the unconformable nature of the junction of the Pniel with the Zoetlief series, thus confirming the conclusions arrived at from a study of the Riet River sections.

The quartzites vary in thickness from 651 feet to 826 feet, and have a dip of between 4° and 5° almost due south; the thinning takes place in a south-south-easterly direction. The same bed of quartzite has been proved in the Wesselton mine, but the shafts at Bultfontein and Dutoitspan are not yet deep enough to reach it.

From the sections of the mine shafts and a plan showing their positions, it is possible to determine the strike of the uppermost bed in the quartzites at a depth of from 600 to 700 feet below the surface. At the Kimberley Mine the strike is nearly east and west, but this curves round to south-east at the Wesselton mine. From this point it passes into the Orange River Colony, apparently with a nearly uniform curvature, and appears at the surface on the north bank of the Modder River, along the Cape Colony boundary line. The quartzites form a little ridge on Voetpad's Drift (Fig. 1), and dip north-westwards below the diabase. Dips vary from 5° to 30°, and the strata are traversed by small flexures having axes trending north-westwards. The thickness of the series cannot be less than 600 feet here.

On Doorns diabase appears below the quartzites and above the rhyolites; westwards on Van Aswegens Hoek this lower volcanic group thickens at the expense of the sedimentary rocks, so that on the Riet River, where there are continuous cliff-sections, the rhyolites are succeeded by diabases only.

The quartzites are followed by basic lavas, which are well-exposed in the railway cutting a mile and a half north of Modder River Station.

At the small cottage on the railway a second quartzite horizon is found, the thickness of which, as shown by a well, is about 50 feet. The quartzites dip towards the north, and are succeeded by diabase. The band is evidently lenticular, as the outcrops cannot be traced more than about a quarter of a mile on either side of the railway.

The Pniel series have thus been bent into the form of a basin between Kimberley and the Riet River, and the upper quartzite just mentioned finds its equivalent in the Bultfontein and Dutoitspan Mines. In these it has a thickness of 129 feet, and a dip to the south-west of between 2° and 3°. The thickness of the volcanic group separating the two quartzite zones has not been proved in any one shaft, but may be estimated at from 450 to 500 feet. It consists principally of compact and amygdaloidal diabases, but in Dutoitspan Mine, between the depths of 550 and 560 feet, there are pebbly grits and tuffs.

The maximum thickness of the Pniel series at Kimberley will be about 1,575 feet.

The nearest outcrop to Kimberley of the diabase is at a point six miles out, a little south of the road to Barkly.

After leaving Kimberley, if we except the Riet River area, no sedimentary rocks belonging to the Pniel series are seen for many miles—not until we approach either Pokwani, Delport's Hope, Schmidt's Drift, or the Orange River.

East of the railway and parallel to it is an anticline extending from Taungs past Pokwani, and bringing up from beneath the diabase a considerable thickness of conglomeratic rocks.

This belt is about 21 miles in length, with an average width of 4 miles; the anticline has been greatly cut into by rivers taking their rise on the plateau to the east, and the western limb is considerably denuded.

The material building up the core of the anticline varies extremely in nature, both along and across the strike, but, generally speaking, it is a gritty felspathic rock, containing pebbles, and passing into an arkose in one direction, and into a conglomerate in the other.

At Taungs the lowest beds exposed are grey grits and quartzites, at least 250 feet thick, along the south side of the Harts River. Just below the Court-house is a cliff of massive blue-black flinty rock, fully 20 feet thick, and forming a shallow anti-

cline pitching towards the north. It is followed by a succession of grits and conglomerates, and the total thickness of strata exposed at Taungs must be fully 500 feet.

The pebbles are either scattered through the rock or crowded together with hardly any cement to form lenticular layers, with a thickness of as much as eight feet.

Immediately north-east of Taungs the conglomerates dip directly below the diabase. About four miles to the south-east, just below the top of the series, is a band of black chert, followed by ashy beds full of masses of amygdaloid, and overlain by sandstones with thin sheets of lava.

The pebbles in the conglomerate are all smooth and water-worn, and are seldom over a foot in diameter, although one of two feet in length was found. They consist of quartzites of various colours, black and banded cherts, quartz-porphyry and orthoclase-porphyry, quartz, and less abundantly felsites, amygdaloids, chert breccia, pebbly quartzite, jasper, and banded ironstones (magnetic quartzites).

The inclusions, especially the quartzites, show peculiar etchings, pits, and circular or oval lines of erosion, while the banded quartzites and cherts have irregular grooves along the planes of bedding. The porphyry pebbles almost invariably have the felspar crystals removed on their exteriors, and sometimes to a depth of a couple of inches the felspar has been changed to a soft pinkish material. Hence such pebbles show deeply-pitted exteriors.

Upon breaking out the pebbles from the conglomerate, it is seen that this etching and pitting must have taken place prior to their having been embedded in the matrix. Very probably the conglomerates were formed off a coast, along the shore of which the pebbles had been rolled and exposed to the weather for a considerable time before their entombment.

Near Pokwani, on the farm Bawtree, in the western limb of the anticline, there appear below the diabase coarse conglomerates, cropping out in great angular and rounded masses, and reminding one forcibly of the conglomerates at Mafeking. A remarkable point is the great abundance of fragments of granite gneiss and pegmatite, along with magnetic-quartzite, ferruginous chert, various schists and vein quartz, all well rounded and often in boulders several feet in diameter. The dip is rather steep beneath the diabase, and there are in a few places thin volcanic flows among the conglomerates.

On the farm Rockdale arkoses occur toward the top of the formation, with the bedding planes feebly developed, and form great rounded masses. They contain small pebbles, quartz-porphyry being the most abundant constituent, and thus recall the conglomerates of Botman's Poort.†

† Annual Rept. Geol. Com. for 1905, p. 239.

On the farm Pokwani the lowest strata exposed in the anticline are seen to consist of very soft greenish shales, followed by grits. Between these and the upper series of grits and conglomerates is a thin sheet of amygdaloid, which on being followed to the south rapidly thickens, and on Eastwood covers a fairly large area. It includes thin beds of grit and pebbly sandstone.

The anticline pitches southwards below the diabase just before reaching the Transvaal boundary line. The volcanic rocks which overlie the conglomerates are generally compact and vesicular diabases; occasionally there are tuffs and breccias, while at the beacon H.2, close to Pokwani Station, they contain quartzitic bands, and are associated with a gritty conglomerate, carrying well-rounded masses of various types of diabases and amygdaloids.

The trigonometrical pile of Kopje Enkel stands upon quartzites and black cherty rocks. Diabase is seen a short distance to the north, and the beds probably correspond to the Pokwani conglomerates.

A most peculiar feature about these conglomerates is that, although they attain such a thickness at Taungs, they are nevertheless absent at Modimoe, where, as already recorded, the diabase rests directly upon the granite. It is clear that the conglomerates have been deposited at the foot of a ridge composed of granite, quartzite, quartz-porphyry, and banded-ironstones belonging to the Kraaipan Formation, rocks which are known to occur along the Harts Valley, in the Bloemhof Division of the Transvaal.

Directing our attention now to the south, we find that these basal deposits of the Pniel series are brought up by an anticline, which extends from Hopetown to Campbell, and which is crossed by transverse flexures.

On the Orange River, just below Hopetown, the beds are exposed on either bank, and consist of various sandstones, quartzites, and grits to a thickness of at least 150 feet. Some of the grits are conglomeratic, and contain rows of little pebbles of quartz and more rarely of dark quartzite. This stone can be obtained in large slabs, and has been quarried for the construction of the road-bridge.

On the south the strata are overlapped by the Dwyka boulder-bed, and on the north they are overlain by a great thickness of coarse volcanic breccias.

The junction with the overlying volcanics is well seen on the left bank of the river, a little above the bridge. On the opposite bank the succession is duplicated by a small fault.

In a deep lateral gorge of the Orange River, on Eskdale, there appears a tiny inlier of the quartzites, overlain by compact diabase. From this point the strata rise, and the quartzites form a dome near the top of the ridge, a couple of miles to the north.

From Summerhill to Clydesdale, a distance of eighteen miles, there are continuous exposures of quartzites along the anticline. In pre-Dwyka times the crown of the anticline was denuded, and an anticlinal valley formed, which laid bare the underlying granite. This valley, but slightly modified, exists at the present day, the greater proportion of the conglomerate and shale which at one time filled it in having been removed by denudation. Both to the north-east and south-west the quartzites form cliffs, while on Summerhill, at the end of the pitching anticline, they give rise to a fine amphitheatre. From Ettrick to Tullochgorum the southern limb of the anticline is faulted, and the granite is brought up against the diabase; the actual contacts are concealed by the Dwyka.

On Clydesdale the arch of the anticline remains intact, and it has a somewhat flattened crest, thus approaching in character a double monocline. The northern limb forms an elevation known as Slijpsteen ("Whetstone") Kopje, which was visited and described by Stow.‡

On Stratford the anticline pitches below the diabase, but the quartzites are brought up immediately beyond by an anticline striking north-eastwards, and form a ridge overlooking Douglas and the Vaal River.

The fold into which the quartzites have been bent pitches to the north-east, while its western limb has been denuded away and hidden by the Dwyka formation and by red sand. A most remarkable feature is the extraordinary false-bedding in the quartzites, very well exhibited a little to the south of the main road to Belmont. The inclination of one set of laminae to those immediately above or below may reach a value of 80°, and in consequence, the deviation of a lamina from the normal plane of bedding cannot be less than 40°. The quartzites are brought up by a similar transverse fold on the right bank of the Vaal River, on the farm Atherton, a little above Douglas, where they contain shaley layers.

The strata exposed in all the anticlines are principally light-grey glassy quartzites. Soft creamy coloured sandstones and arkoses are represented as well, commonly in the middle portion of the formation; they have been utilised for building purposes and for grindstones.

On Hereford a well passes through the base of the formation into the granite, the strata consisting of flaggy sandstones, micaceous shales, and arkoses. On Summerhill the beds resting directly upon the granite are hard quartzites.

The quartzites are occasionally gritty, and contain small pebbles of quartz; they are sometimes traversed by small irregular quartz veins. The thickness of the formation must be somewhere between 200 and 300 feet.

‡ G. W. Stow, *loc. cit*, p. 597.

In Herbert the rocks which succeed the quartzites are entirely of volcanic origin, *e.g.*, diabases and amygdaloids, flinty-looking rocks, light-coloured (probably andesitic) lavas, breccias, etc.

East of Schmidt's Drift there are a few outcrops of quartzites in the midst of the volcanics. At Hofmann's Pan there are flags and white quartzites, both overlain and underlain by diabase and about 25 feet in thickness. The same horizon is probably represented by quartzites and flags on Klip Fontein, about six miles to the north, at the foot of the great ridge flanking the Vaal River. A fold brings up the same band midway between Hofmann's Pan and Schmidt's Drift, on the north side of the main road.

The uppermost zone, characterised by the presence of porphyritic lavas, occupies small areas on both banks of the Vaal River below Waldeck's Plant. The lavas dip towards the north-west, and consist of green compact diabases, carrying large felspar phenocrysts.

On the farm H.V. 47 there is an intercalation of quartz-porphyry, which is more or less on the same horizon as the quartz-porphyry forming two kopjes at the extreme southern corner of Drooge Veldt. These little hills rise from a base of diabase, and the rock of which they are composed is sometimes vesicular and shows fluxion structure.

Patches are also seen on Klip Fontein, within two miles' distance, but are more slaggy and seem to be less acid. From Waldeck's Plant to Delport's Hope there are alternations of diabase, amygdaloid, porphyritic diabase, and breccias, and at Sydney there is an intercalated bed of quartzite, not more than 20 feet in thickness. The quartzites weather with a rough brown exterior, and contain great numbers of spherical concretions from a half an inch to an inch in diameter. Certain gritty bands contain small quartz pebbles up to a quarter of an inch in size. The strata are affected by gentle folds trending north-eastwards; the general dip is down the river. The quartzite is succeeded by very coarsely porphyritic diabases, which are well exposed on the left bank of the Vaal only.

Porphyritic diabases are found in a few other localities, but it is not certain whether they belong to this or to a lower horizon. For example, they appear on Graspan, midway between Kimberley and Schmidt's Drift, at Koppie's Kraal on the Riet River, and at the southern corner of Stratford, on the Orange River.

Lithological Characters.—The lavas are usually so greatly altered that it is only in few specimens that the original minerals can be made out.

A compact variety from Riverton shows in thin section (1560) granules and prisms of quite fresh augite accompanied by a little chlorite, epidote, and calcite. The felspar is in the form of stout laths, and appears to be andesine.

Mr. Rastall has given a description of several lavas from the Kimberley mines,‡ while De Launay* has given a few analyses of the diabases.

The porphyritic lavas appear to have phenocrysts of orthoclase; these may attain a length of an inch. In thin section (1573) the greenish-yellow waxy-looking felspar is found to be altered entirely to epidote and zoisite, but the ground mass consists of minute plagioclase laths, small augites, and a little epidote and sometimes quartz. In many of the lavas the augite has been entirely converted into fibrous hornblende (uralite). Some of the more acid-looking varieties may be andesites or dacites, while trachytes may also be represented.

A remarkable feature about the Pniel volcanics is the great proportion of brecciated igneous material in them, which sometimes forms beds from 25 to 50 feet in thickness, traceable for miles. The breccias are often veined with black cherty material, possibly representing fine sediment, which was deposited in the spaces between the rock fragments. Some lavas contain oval or rounded masses of volcanic rock of a more acid type, and resemble the variety known as "pillowy-lava."

Pipe-amygdaloids are not uncommon. Good examples were obtained from the Kimberley Mine and from Rust-en-Vrede and Gras Randt, both on the Kimberley-Schmidt's Drift road. Lavas containing "vesicle-cylinders" are numerous, for example at the town of Barkly West and at Niekerk's Rush.††

Fissures of Eruption.—No vents or fissures from which the Pniel volcanics could have issued have yet been found. There are, however, many peculiar veins or dykes of felsitic material, which are confined chiefly to the farms Klip Fontein and Rooi Poort, north-east of Schmidt's Drift. Their course is nearly east and west, and their outcrops run in straight lines, regardless of the contour of the diabase surface. They vary in width from a few feet up to ten or fifteen, and though well-defined from the surrounding diabase, do not appear to have sharp junctions.

These dyke-like masses consist of light pink or cream-coloured felsitic rock, mostly compact, sometimes vesicular, and are commonly much brecciated and silicified. As there are outliers of acid amygdaloid and quartz-porphyry a little to the east, I think that possibly these dykes mark the sites of fissures from which the higher-lying acid volcanics may have issued. At the junction with the ascending acid magma, the diabase would be partially fused, and there would necessarily be an intermixing of the two materials.

Conditions Attending the Formation of the Pniel Series.—In the area to the north it was pointed out in last year's Report that the floor upon which these rocks were formed was an ex-

‡ Rept. South African Assoc. Adv. Sc. for 1906, p. 272.
* De Launay. Les Diamants du Cap., p. 109. Paris, 1897.
†† Geological Magazine, p. 15, 1907.

tremely diversified one, probably an old land surface. In the south this surface seems to have been much more even and regular, and very probably a submerged area.

The oldest rocks are the lava flows succeeding the rhyolite at Kimberley and on the Riet River. This preliminary volcanic outburst was succeeded by a period of sedimentation, during which from 200 to over 800 feet of quartzites and conglomerates were deposited, evidently over a wide area.

With the Taungs conglomerates must be grouped those of Botman's Poort, the exact position of which was uncertain at the time of writing the last Report. Similar quartzites and conglomerates have been found below the diabase in the neighbourhood of Schweizer Renecke, Wolmaranstad, and Kunana by Mr. Holmes, and at Klerksdorp by Dr. Jorissen,† from which it seems very probable that they represent the Elsburg Series of the Witwatersrand.

The pebbles which the conglomerates contain, together with more direct evidence, indicate an unconformity with the granite, the Kraaipan formation, the Witwatersrand formation, and the Zoetlief beds.

That the succeeding period of volcanic activity was accompanied by sedimentation is indicated by intercalations of volcanic and sedimentary material, but in the north, and perhaps in places to the east as well, the volcanic rocks rest directly and unconformably upon much older formations. There is accordingly a great overlapping of the volcanic rocks, and the lavas occupy a tract far exceeding in size the area covered by the sedimentaries.

In Prieska the diabase rests directly upon the older formations, and it seems probable that the original basin was limited to the interval between Vryburg and Prieska. Already the quartzites along the Orange River show by their diminished thickness the nearness of the source of the sedimentary material.

III. THE BLACK REEF SERIES.

Owing to the wide area occupied by the Dwyka formation in the valleys of the Harts, Dry Harts, and Vaal Rivers, the Black Reef series is but infrequently exposed. After leaving Dry Harts Siding, the formation first appears at Borrell's Kopje, near Delport's Hope.

The rocks are flagstones and quartzites, which are succeeded on the west by limestones and dolomites with interbedded shales. A couple of miles east of Delport's the beds form an irregular dome, the strata being chiefly green or grey flagstones. West of the Vaal River, from the Barkly West boundary as far as Douglas, the Black Reef series forms disconnected outcrops, and has a low dip towards the Kaap Plateau.

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† G. G. Holmes, Trans. Geol. Soc. S. A. Vol. IX., p. 93.
E. Jorissen, do, do. do. p. 41

On the farm Roode Kopjes, midway between Douglas and Campbell, the strata are bent into a dome, the core of which is formed by amygdaloidal diabase. A similar though much smaller dome is seen to the south. The western beacon of Brij Paal Commonage stands on the hill which it makes.

On the east of the Vaal River, near Schmidt's Drift, there are two patches of Black Reef, the larger of which, on Zaand Plaat, forms a somewhat flat-topped hill.

Lithological Character of the Black Reef.—Throughout this area this formation is of very similar character to the Black Reef series in the Vryburg Division.

Usually it is rather flaggy, and some of the material can be termed shale. Such soft greenish shales are very well developed towards the base of the series east of Schmidt's Drift, and are excellently exposed in the cuttings along the main road in its descent to the pont. In some localities, *e.g.*, N.W.4 and N.W.5, on the Barkly West boundary, the material is altogether a massive quartzite, and a full section from the diabase up to the Campbell Rand series is seen on the side of the ridge carrying the boundary beacon. Usually the formation becomes shaly towards its upper limit.

Thin limestones and dolomites then appear, and become more and more numerous, until the shales form an insignificant proportion. It is thus rather difficult to draw a sharp divisional line between the Black Reef and the Campbell Rand formations.

Dark green quartzites are well represented, while at Schmidt's Drift there is an intensely black massive quartzite, sometimes carrying large inclusions of black-green chert, containing rhombohedra of siderite. These cherts have all the appearance of boulders, but are more probably concretions. On N.W.3 this variety of chert forms a bed nearly a foot thick, and is crowded with rhombohedra of siderite about one-third of an inch in size. It also forms oval, round, flattish, or irregular masses in the quartzite, while there are as well beds of cherty flagstone with much smaller rhombs. The carbonates usually weather out, and leave honeycombed masses of chert.

Grits are very rare—I only noticed them on the northern part of Roode Kopjes—while conglomerates are absent.

The thickness of the formation appears to be wonderfully uniform, and ranges from 150 and 200 feet.

Relation to the Ventersdorp System.—There are but few sections where the relationship of the two formations can be studied, but the unconformity which they indicate seems to be of no great magnitude; this is a confirmation of the views expressed as the outcome of the work done further north.

At the southern kopje east of Delport's Hope, the base of the Black Reef is found to transgress from a quartzite interbedded with the diabases on to the diabase overlying this intercalation.

The dip of the latter is much greater than that of the overlying flaggy quartzites.

On N.W.4, just behind the homestead, the basal quartzites rest upon a massive bed of felsite, which is sometimes compact, sometimes amygdaloidal, and often brecciated. The quartzites for a short distance above the base contain fragments of the felsite; one layer is a breccia of felsite fragments in a dark quartzitic ground mass.

To the south the base of the Black Reef comes into contact with basic lavas and breccias, so that there is evidently an unconformity.

It is difficult to be sure what horizons diabases seem to belong to at the various contacts with the Black Reef. I think that the highest zone of the Pniel group is probably represented near Delport's Hope.

IV. THE CAMPBELL RAND SERIES.

From the edge of the Kaap Plateau for many miles westwards extend rocks belonging to this formation. The escarpment does not mark its eastern limit, for patches are found on the slope towards the Harts-Vaal River. The feature is due to erosion in pre-Dwyka times, and a deep gorge must have existed, coinciding almost exactly with the course of the present Harts-Vaal River. This valley was filled in with Karroo beds, and is being re-excavated by the present rivers. The cliff-face varies from 300 to 500 feet in altitude, but must have been much higher originally. West of Delport's Hope the shales still abut against the cliff of limestones, etc., to form a gentle slope, up which the main road to Daniel's Kuil has been carried. The same thing is seen at Boetsap.

Towards Vryburg the divisional line between this formation and the Black Reef series is sharp, and the limestone and dolomite occur in rather thick bands, separated by hard greenish flags. Further south the formation includes a great deal of soft bluish-black shale, and there is a gradual passage into the Black Reef series. North-west of Schmidt's Drift there are splendid sections showing beds of soft shales, sometimes over 50 feet in thickness, alternating with massive layers of limestone and dolomite. On the farm N.W. 71, where there are five such hard bands in the face of the escarpment, one is reminded very much of the flat-topped hills of shale with "defining" sandstone of the Karroo. Some of the Campbell Rand shales are carbonaceous and pyritic, for example at Klip Fontein, midway between Schmidt's Drift and Douglas.

The peculiar unconformity seen at Leij Fontein has been fully described by Mr. Rogers in the last Annual Report.† It is on

† p. 153.

a horizon at least 500 feet above the Black Reef, and probably somewhere nearer 1,000 feet. It is very interesting to note that the great anticline affecting the Pniel series, and extending from Hopetown to Douglas, continues through the Roode Kopjes to the boundary line between Leij Fontein and Campbell Commonage. It thus seems probable that the anticlinal fold originated, or was partly produced, during the deposition of the Campbell Rand rocks. The lower strata at Leij Fontein have been tilted towards the west and denuded. The unconformity probably runs across the commonage, through the village of Campbell, but the exposures are not numerous enough to determine its position accurately. The eastern limb of the anticline is seen in the escarpment just west of the entrance to the Campbell ravine.

Toward the base of the Campbell Rand formation oolitic limestones are very numerous, and, though only in thin bands, often form horizons that can be followed for miles. The oolitic structures have often the size of a pea.

The limestones are all blue-grey in colour and more or less dolomitic in composition. They contain chert and cherty quartzite, either as beds, lenticles, or irregular masses. The limestones are traversed by little veins or threads of quartz, sometimes forming a network, at other times distributed through the rock in the form of little crystals or crystal aggregates. Analyses of some of these limestones have been given by Mr. R. B. Young.*

V. THE DWYKA SERIES.

The greater portion of this area is occupied by rocks belonging to the Dwyka series, showing that the patches described in last year's Report were but a remnant of a widely spread sheet of deposits of Karroo age.

As in the western part of the Cape Colony, the formation can be roughly divided into two portions: the lower consisting of a boulder-bed and the upper of shales. In this part of the Colony, however, it is impossible to distinguish these divisions upon a map for the following reasons:—*Firstly*, the beds are often hidden over considerable distances by superficial deposits, such as sand, tufa, or gravels; *secondly*, there are often alternations of shale, boulder-shale, and conglomerate towards the base of the formation; and, *thirdly*, erratic boulders occur at a number of localities embedded in the shales at a horizon far above the base of the formation.

The uppermost division of the Dwyka series is constituted by the "white-band," which consists of white-weathering carbonaceous shales. Strata above this horizon will be regarded as

* R. B. Young, Trans. Geol. Soc. S. A. Vol. IX., p. 58, 1906.

belonging to the Ecca series. This classification was adopted by the Geological Survey in 1897, and its practical utility has been confirmed by each succeeding report. The use of the term Ecca to describe the shales immediately succeeding the boulder-beds in this area (sometimes known as Kimberley shales) is therefore inadvisable, as these beds are not on the same horizon as the Ecca beds of the southern and western Cape Colony as defined by the Cape Survey.

There can be no doubt that the Dwyka boulder-beds have been laid down under glacial conditions. This area has yielded much information concerning the conditions that prevailed during their formation; but many problems, nevertheless, suggest themselves, which can only be solved when some of the difficulties which still beset the study of pleistocene glacial geology have been cleared up.

Surface upon which the formation rests.—Everywhere the Dwyka lies unconformably upon older rocks, over a large area chiefly upon the diabases of the Pniel series. It overlies an undulating surface, at one time a tract of highly diversified land sloping gradually toward the south-west. This surface was intersected by a number of valleys, some of considerable width and depth, extending in a north-north-easterly direction.

During and immediately following the period of glaciation these valleys were filled in with glacial deposits and shales, but the extensive denudation which has taken place since Cretaceous times has re-excavated these ancient valley systems, the softer Karroo deposits being eroded more easily than the hard pre-Karroo rocks. In consequence the courses of the present rivers coincide very closely with those of the ancient continent, as, for example, the Harts-Vaal River. The contours of the ridges formed by the older rocks are smoothed and rounded, and are typically those of a glaciated region; in the case of the escarpment of the Kaap, however, solution of the limestone has effaced all evidences of glaciation.

Variation in altitude of the floor.—So irregular is the floor that it is extremely rare to find any considerable area over which it has even an approximately uniform slope.

Between Riverton Road and Windsorton Road Stations there is a large flattish tract which extends eastwards for a number of miles into the Orange River Colony. Numberless little hummocks of diabase project through the thin covering of Dwyka, and are in places so abundant that it is almost impossible to map all these tiny inliers. The longer axes of the greater number of these inliers strike in a south-westerly direction, and they are apparently the exposed tops of buried parallel ridges.

In the Harts Valley at Taungs, the variation in altitude of the base of the Dwyka is not less than 800 feet, see Fig. 3, while north of Schmidt's Drift variations of from 400 to 500 feet in altitude are found within remarkably short distances. The same is the case at Douglas; along the Orange River Dwyka is found right down in its bed, while to the north, diabase and quartzite rise above it to an altitude of close upon 700 feet. Everywhere are seen little patches of conglomerate adhering to steep faces of rock, while in not a few localities the conglomerate lies banked up against a steep cliff which originally must have had an altitude of from 200 to 300 feet. As already noted, the present escarpment of the Kaap represents such a feature, and must have had a face rising from 500 to probably over 800 feet in height.

When the minor undulations are considered, it is found that changes in level of the old surface are often very abrupt, and that the slope frequently approaches the vertical; in one case south of Schmidt's Drift a face has even been undercut.

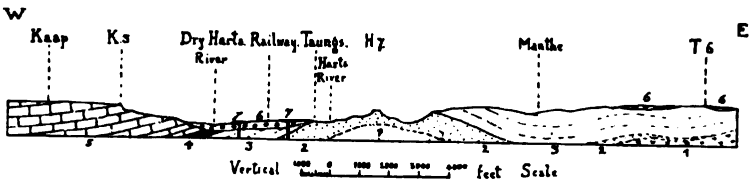

FIG. 3.—Section from Kaap Plateau to Transvaal bordei, distance 27 miles. 1, granite; 2, conglomerates; 3, diabase and amygdaloid; 4, Black Reef series; 5, Campbell Rand series; 6, Dwyka series; 7, dolerite.

Glaciated rock-basins.—That the irregularities of the surface are due principally to sub-aerial and to river erosion in pre-Dwyka times admits of no doubt, but there is considerable evidence to show that glacial erosion has played no small part and has to a certain degree modified the original contours. The valleys have been smoothed and protuberances rounded off, while rock-basins have in a number of instances been excavated. These basins vary from shallow depressions a few yards in diameter to hollows a mile or more across and of pretty considerable depth.†

We have a very good example about a mile to the south-east of Riverton, with a length of a mile and a half, and a width of not more than half a mile; it is surrounded by a ridge of diabase. Another basin filled in with shale occurs about 2 miles to the south-east of the Leicester mine near Klipdam. It is economically of great importance, since wells sunk in the shale yield splendid supplies of water. Other basins are found to the north, as, for example, at the Cyrus Mine. Probably they are quite

† See Ann. Rept. Geol. Com. for 1905, p. 251.

numerous, but, in most cases, owing to incomplete denudation, the rim of diabase cannot be traced completely round the lower-lying shale and conglomerate.

The presence of such glaciated rock-basins has determined to a great degree the formation of pans in this area; this will be discussed more fully later on.

Direction and effects of glaciation.—The glaciation of rock-surfaces has been well described by Messrs. Young and Johnson* at various points between Riverton and Prieska; similar striated surfaces have been found at numerous localities, chiefly along the Vaal River.

In the majority of cases the direction of glaciation is from the north-east to the south-west; the following table gives some of the values obtained, the angles in all cases being measured from the true meridian:—

Modder Hoek, H.V.7 (Barkly West)	S. 50° W.
Riverton	S. 81° W.
Kimberley Mine (south side)	S. 50° W.
Pniel	S. 27° W.
One mile north of "The Bend"	S. 37° W.
One mile south-east of the Barkly West Bridge	S. 30—40 W.
H.V. 47 (Barkly West)	S. 54° W.
Longlands	S. 15°—45° W
Schmidt's Drift (east of river)	S. 21° W.
R. 26 (Herbert)	S. 10° W.
Banks Drift (Riet River)	S. 38°—80° W.
Roode Kopjes (between Campbell and Douglas)	S. 55° W.
Backhouse (Douglas)	
Ettrick (Orange River)	S. 42° W.
Hopetown (bridge)	S. 90° W.

Upon comparing the values, it will be noticed that they show a considerable variation, though the mean is very nearly due south-west.

Now it has already been remarked that the pre-Dwyka valleys and depressions have a south-westerly trend, to be more accurate, a bearing of from S. 15°—45° W., usually somewhere about S. 30 W.

This shows that the ice-sheet has crossed the ridges and depressions *obliquely*, and that the movement of the ice has to a great extent been uninfluenced by the contour of the ground.

In accordance with the experience gained in a study of pleistocene glaciation in the Northern Hemisphere, one would be led to expect a deflection of the lower portions of the moving ice along

*. R. B. Young and J. P. Johnson. Trans. Geol. Soc. S. A., Vol. IX., p. 34, 1906.

the bottom of these valleys while the upper portion overrode the ridges without appreciably diverging from its course. In but few cases is this true here; in the majority the direction of movement seems to have been independent of the ridges and valleys.

A little to the south of Schmidt's Drift the ice appears to have impinged on the ridge of Black Reef quartzites forming the right bank of the river and to have been deflected in a more southerly direction almost parallel to it. Close beside the road at the boundary between R. 26 and R. 27 the quartzites are undercut and show a striated face sloping inwards, while just below it the flags are tilted on edge and the glacial material thrust in beneath them.

The direction of striation is S. 10 W., whereas on R. 25 and 24 (Sivonel Location) it is S. 28 W. Even here, however, the glacial striae are oblique to the *roches moutonnées*, for on Sivonel the longer axes of these hummocks point a little to the *east* of south.

The remarkable parallelism of the hollows formed between these hummocks either points to an old river system with an extraordinarily regular arrangement of tributaries or else argues their excavation by ice. It is, however, difficult to see how a sheet moving in a certain direction could cut in the underlying rock deep grooves which are arranged obliquely to its direction of movement.

It seems more feasible to suppose that the ice-sheet had during its earlier stages a movement directed more towards the south, and that ultimately its course was deflected in a westerly direction, and practically all traces of the more southerly glaciation obliterated by continued erosion.

There are certain irregularities in the distribution of erratic blocks in the boulder-beds which can be very well accounted for on this hypothesis; it must nevertheless be made clear that the evidence is not as good as one could wish for. Little additional light is thrown on the question by the presence of cross-striae.

Cross-striae.—On all glaciated surfaces there is a slight crossing of the striations. As a rule the flatter the surface the greater will be the distance over which the striations maintain their parallelism; the more inclined the face the greater is their divergence.

At Banks Drift, on the Riet River, there are flat surfaces showing two sets of striations, one running S. 38 W. and the other S. 80 W.; in places there are striae intermediate in direction. Here the more westerly striae partly obliterate the others, which tends to support the hypothesis stated above.

Near Riverton the opposite is the case. About three miles to the north-west at the bend of the Vaal (Khosop's Kraal) are fine *roches moutonnées* having remarkably steep surfaces; on these rests the boulder bed.

At the northernmost outcrop there are long furrows in the glacial material, a few feet wide and up to two feet in depth; they are exposed over a length of 250 feet and have a constant inclination, rising gradually to the south-west.

The material seems to have been gouged out by the ice-sheet; large boulders embedded in this glacial "pavement"† show striations parallel to the direction of the furrows and ridges. A hummock of diabase has protected the glacial conglomerate on its south-west side from complete removal, and has been instrumental in the formation of the pavement. The striations continue evenly from the furrows on to the crown of this diabase hummock, and cross the older and more westerly-directed striae.

The furrows are in some places filled in with more boulder material, in others they are overlain by greenish shales.

Effects of ice pressure.—The production of the glacial pavement just described is an extremely good example of the shearing away of the glacial material covering a ridge. At a number of places in the vicinity the conglomerate is traversed by planes of shear, groovings, etc. At the south side of the bend in the river the diabase is overlain by fine-grained quartzitic material showing striations, often throughout its mass, and troughs and ridges parallel to the direction of glaciation just like the conglomerate.

At Pniel, a short distance from the Kimberley boundary fence, a pale green laminated sandstone, carrying large erratics rests directly upon the diabase. The dip coincides with the inclination of the underlying rock, but at a couple of points the shales have been bent into sharp anticlines probably through pressure exerted by the moving ice-sheet.

To this shearing action of the ice-sheet rather than to subaerial denudation succeeding the period of glaciation may be ascribed the absence of conglomerate in such places where the shales are found abutting against steeply inclined glaciated surfaces or on the crests of glaciated ridges. The squeezing of the glacial material into the flagstones of the Black Reef series south of Schmidt's Drift has already been noticed.

On the left bank of the Vaal River about three miles below Windsorton, the diabase floor is traversed by well-developed joints. The ice-sheet has torn out blocks of diabase about three feet across, and the spaces are now occupied by conglomerate. The "plucking" on the south-west side of joints has been noticed by Messrs. Young and Johnson.

Transport of boulders.—The direction of movement indicated by the striae is confirmed by the examination of the contents of the glacial material, most of the boulders being of rocks which are found ***in situ*** to the north-east.

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† For a description of a similar "boulder-pavement" see the Ann. Rept. Geol. Com. for 1903, p. 21.

Diabase and amygdaloid are invariably predominant; quartzites, quartz-porphyries, and granites less numerous. The Red granite of the Bushveld area of the Transvaal is not common, but its presence shows that some of the boulders have travelled a great distance.

The rhyolites of Klokfontein and of the Riet River are abundant along the Orange River between Mark's Drift and Ettrick. The Dwyka between Schmidt's Drift and Campbell is crowded with fragments of Black Reef quartzite, while close in under the escarpment blocks of the Campbell Rand limestone and chert are numerous, *e.g.*, Kalk Dam and Roode Kopjes. South-west of the granite and quartzite exposures on Ettrick and Hereford are abundant erratics of those rocks.

Much of the material in the Dwyka is of local origin, and in certain cases the inclusions still preserve somewhat angular outlines, for example, in the case of the quartzite boulders at Delport's Hope, which are derived from the ridges lying a little to the north-east.

The boulder beds.—Speaking generally, in the eastern portion of this area, there is a single boulder-bed of no great thickness, succeeded rather abruptly by a series of fine-grained dark shales and fissile sandstones.

The rock is too hard to be called a boulder-clay, while the scarcity of boulders in certain portions prevents the general employment of the name conglomerate; the terms moraine and ground-moraine are hardly justified until we know more about the conditions under which the deposits were formed. Prof. Penck has recently suggested the name "*tillite*," a term which is certainly very convenient to employ.

The rock is harder here than in the neighbourhood of Vryburg, but otherwise has much the same character. It includes numerous boulders of all sizes, mostly well smoothed and striated, while the matrix is a pale bluish, brownish, or greenish gritty material.

The thickness of the boulder-bed varies considerably within short distances; it may be as much as 30 feet or more in one place and thin out to nothing a short distance away.

Generally speaking, it is thicker over the hollows in the floor and thinner over the ridges. Its upper surface reproduces the contours of the floor, but the irregularities are always flattened out. The shales following have frequently dips of over 30° in the vicinity of ridges.

In the lower part of the Riet River, on the farm Badenhorst Fontein, there rise from a terrace cut in the soft shales several mounds strewn with boulders, and which indicate the presence underground of little knobs of diabase over which the boulder material had been evenly spread. Similar mounds covered with boulders occur to the north-east of Schmidt's Drift.

The boulder-bed is replaced by sandstones and pebbly sandstones along a line running in a south-westerly direction from near Modder River Station to the Orange River.

These sandstones are well seen along the Riet River where they rest upon the granite inlier mentioned at the beginning of this Report.

They are massive sandstones of a pale buff pink or green colour, and have been much quarried, as they furnish a building stone of excellent quality. The bottom layer is softer and contains a few boulders. Thick greyish micaceous sandstones appear in the drift and include thin bands of black shale.

On the farm Doornlaagte a well has proved similar sandstone at a depth of 80 feet.

On the farms Boschman's Pan, Glasnivon, Hayfield and Burton, greenish or purplish gritty sandstones crop out or have been proved in boreholes and rest directly upon diabase. At Kababas Pan there are fine exposures of sandstone both round its south-western side and within the pan itself. They are fine-grained greyish green varieties carrying little flakes of white mica. Bedding planes are but feebly developed, and the rock contains very large concretions and sheet-like masses of hard calcareous sandstone of a yellow-brown colour. In these beds are found small boulders of diabase, granite, quartzite, porphyry, etc., sparsely distributed through the rock and gathered together along certain horizons. The inclusions are well rounded, but no glacial striations were visible on any of them.

Close to a little pan at the south-western corner of Glasnivon these sandstones are exposed and have a purplish tint; they are crowded with well-striated boulders.

To the south-west of this point the Dwyka becomes more normal; but, again, on Ettrick, close to the Orange River, the boulder-bed is overlain by crumbly yellowish sandstone with thick calcareous layers, and is often very gritty.

This belt of gritty and pebbly sandstones has been formed along an old valley, and perhaps represents material which has been brought down from the north-east by a post-glacial river. They are succeeded invariably by dark shales and mudstones.

Glacial deposits of an entirely distinct type are found in the Harts-Vaal River Valley, and are confined almost wholly to this portion of the area surveyed; similar conditions appear to have extended for short distances up the Orange and Riet River valleys.

Briefly stated, this type consists of alternations of "boulder-shale," "gravel-Dwyka," "bedded-Dwyka," shales and limestones, followed by black shales in which boulders are frequently present. A short account of some of these different varieties of deposit will therefore precede the description of the sections in which they are found.

(*a*) *Boulder-shale.*—This consists of a fine-grained bluish or blackish-green shaly material, in which are set rounded and well-striated boulders of various rocks of all sizes, with no definite arrangement or orientation. The shaly character may in part be secondary and due to pressure.

Attention has been directed by Messrs. Young and Johnson to certain bands which are enclosed by the boulder-shale and lie at all angles. Owing to their superior hardness they project above the surface of shale and form ribs and dyke-like masses. The material of which they are composed varies from a sandstone to a conglomerate. Sometimes the shales in which they occur are contorted, indicating the effect of pressure, but in most cases these gritty bands have been deposited in their present positions.

Through the addition of gritty material the boulder-shale passes on one hand into the normal type of glacial conglomerate and on the other into the variety noted below.

(*b*) "*Bedded-Dwyka.*"—Consists of a gritty and well stratified material, in which are set pebbles and boulders, usually of small size and generally striated.

(*c*) "*Gravel-Dwyka.*"—This is a rather peculiar variety, and consists of an aggregate of little angular or irregularly-shaped fragments of rock with a very small proportion of binding material. These fragments are small, seldom more than a couple of inches across, and very rarely show smooth outlines; they are all of hard material such as quartzite, quartz, and chert.

The rock is dark greenish in colour, and forms beds, lenticles, or irregular masses in the midst of shale or boulder-shale. Being very hard, lumps of it often strew the surface of the ground and thus resemble inclusions in the glacial beds.

"Gravel-Dwyka" probably owes its origin to the melting of masses of ice charged with little fragments of rock.

(*d*) *Limestones.*—All the glacial deposits contain a certain amount of carbonate as a cement. Sometimes the amount becomes so great that an impure limestone or dolomite results, which forms concretions or beds. These calcareous rocks resemble to a considerable degree in their mode of weathering the limestones and dolomites of the Campbell Rand series. Commonly they are fine-grained with little or no visible crystalline appearance; sometimes they exhibit the structure known as cone-in-cone. An analysis of such a rock has been given by R. B. Young† under the designation "Ecca Limestone."

Very often the calcareous material takes the place of the matrix in the glacial conglomerate, and extremely tough conglomeratic masses are produced more or less concretionary in character.

† R. B. Young, Trans. Geol. Soc. S. A., Vol. IX., p. 63, 1906.

The finest section in which all of these varieties of deposits can be studied is found along the south bank of the Riet River, a few miles above its junction with the Vaal (on the farm De Kalk).

The river makes a great bend, and flows at the base of a cliff about one hundred feet in height and almost a mile in length. The strata has been protected by a capping of calcareous tufa and gravels, and an unusually steep face has in consequence been produced.

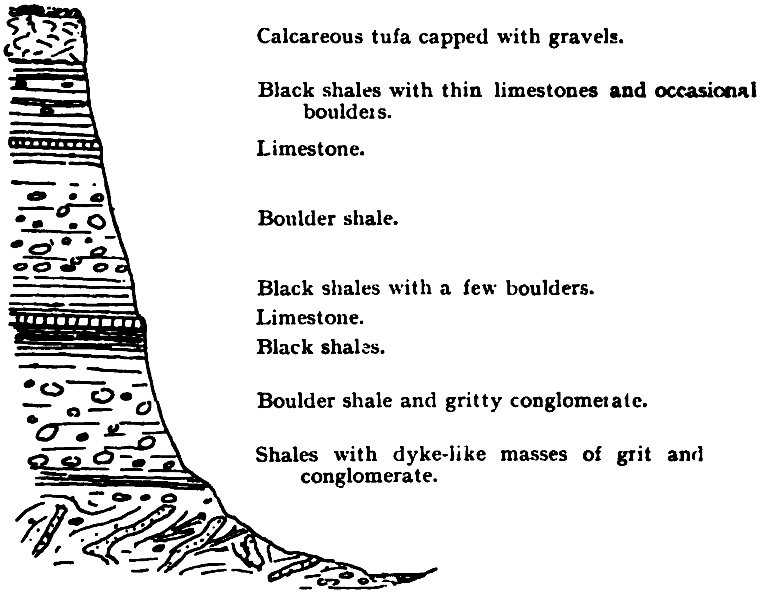

Fig. 4.—Section on Riet River at a point four miles above its junction with the Vaal. Height of section about 100 feet.

The section (Fig. 4) shows shales and boulder-shales, with the peculiar ribs of grit and conglomerate already recorded, at the foot of the cliff; the base of the Dwyka is, however, not seen here. Then follow boulder-shale and gritty boulder-rock with numerous large and well-glaciated inclusions. Next come black shales containing a few scattered boulders, and then a very persistent limestone band, varying in thickness from 6 to 18 inches; the succession is partly repeated, the uppermost strata consisting of black shales and thin limestones and containing occasional boulders always well striated. To the north they are followed by dark fine-grained sandstones and flagstones.

On the farm Atherton, close to Douglas, but on the right bank of the Vaal, there is a fine cliff of boulder-shale fully 80 feet in height; the material is rather uniform in nature, but there are

irregular lenticles and bands of gravel-Dwyka; the finer-grained portions are composed principally of angular debris, while the coarser are full of large glaciated boulders. Diabase and diabase breccia form ridges and islands in the river at the base of the cliff.

On St. Clair and Backhouse there are similar exposures of boulder-shale with layers of shale and bedded or gravelly material. The rock at the base of the formation is usually very hard.

A description has been given by Stow* of a succession behind the old church at Backhouse; the strata are not very well seen here, however, and it seems that he must have obtained his section by piecing together the results obtained from a number of exposures. Since the dip of the the formation and the character of the material changes from point to point, it is very probable that Stow has reckoned the same bed more than once, more especially as the floor of diabase is exposed up the river and behind the old church.

Fine exposures of glacial beds are found on the Vaal River at the Sivonel Location (R. 24) between Douglas and Schmidt's Drift.

The boulder-shales are traversed by gritty ribs and bands, and there is much gravel-Dwyka, calcareous bands and patches, and beds of gritty stuff. The material is well-bedded and the boulders are arranged in layers which can be followed for long distances along the cliff face.

North of Schmidt's Drift, both on the east and west sides of the river, the shales contain beds of limestone, some of which attain a thickness of two feet.

In the Harts River Valley boulders are found in a few localities in the shales at a considerable distance above the base of the formation.

On the Majagoro Location there is a little flat-topped ridge, close in under the escarpment of the Kaap, formed by greenish shales with a thin cap of sandstone and dolerite. Embedded in the shales are boulders of granite, pegmatite, gneiss, diabase, grit, chert, dolomite, etc., some of them being well striated, others being but slightly rounded or angular.

Further down the valley, on the west side of Cornforth Hill (Shaleng) are shales with large calcareous concretions and numerous foreign boulders.

Other localities are Rutland's Drift and a point about four miles east of Espag's Drift on the road to Border Siding.

Similar geological conditions must have prevailed along the lower part of the Riet River. On the north-east side of the farm Kaffir's Dam, about a mile from the river, there is a conical hill composed of blackish shales with calcareous ribs and nodules, and crowned with a little pyramid of dolerite.

* G. W. Stow. Quart. Journ. Geol. Soc. Vol. XXX., p. 598, 1873.

In the shales are boulders of granite, quartz-porphyry, diabase, quartzites, dolomite, etc., sometimes over a foot in diameter. They are smooth and coated with a film of greenish shale, but no undoubtedly striated ones were found. This horizon must be at least 200 feet above the top of the boulder-bed, for the latter is well exposed along stream courses close to the bank of the river.

Conditions under which the boulder-beds were formed.—Just as in the Northern Hemisphere, so also here it is difficult to imagine the exact way in which the glacial deposits have been formed. The commonly accepted view of a boulder-bed or sheet of till as being a "ground-moraine" and having been formed below a sheet of ice is perhaps hardly in accordance with observations, nor does it adequately explain all the facts.

Judging from the evidence in this area, it seems to me that all these various deposits have almost without exception been formed *beyond the ice-front, and during its retreat* in a northerly or north-easterly direction.

Over the high ground the glacial material would be deposited continuously by the melting of the ice, etc.; while in the valleys (*e.g.*, Harts-Vaal) where the old floor was submerged the deposit would be more or less regularly bedded. Beyond the ice-front material would be deposited by floating ice, while subglacial streams would transport gritty and finely divided stuff. The scouring action of running water in certain of the valleys might lead to the partial or complete removal of the glacial material and the formation of fluviatile deposits.

The retreat of the ice-front would not necessarily be continuous, and an advance would result in the ploughing up of the earlier deposits and the production of boulder-pavements.

As the ice retreated the crust of the earth subsided, and the boulder-beds were succeeded by shales and mudstones, with thin sandstones. The occurrence of sporadic boulders in the upper shales indicates the presence of floating ice. This points to a somewhat protracted period of glaciation.

The Upper Shales.—The shales overlying the boulder-deposits consist of blue, green, or black shales, hard mudstones, occasionally flagstones and thin beds of grey and dark sandstone. These are the Kimberley shales of Professor Green. Some of the shales have calcareous and ferruginous concretions, and often they contain a considerable amount of iron pyrites. Indistinct remains of plants are frequently met with.

The thickness of these shales very seldom exceeds 300 feet.

The upper portion of the shales is highly carbonaceous, and on weathering becomes perfectly white, thus forming what is known as the "White-Band."

The White Band.—The shales are hard and fissile, pure white, with sometimes a slightly grey tint. They contain bands of reddish shale and highly ferruginous and ochreous ribs. Limestones are rather rare and the chert band so well seen in the western and southern Karroo is absent; some of the shales, however, have small cherty concretions.

The white band is seldom well exposed. It is usually overlain by dolerite, and fallen material commonly hides the outcrop. There are good sections just north of the Orange River along the railway, while a few miles to the east there is a conical hill of white shale on the farm Suffolk.

Continuous sections are present on Devondale and Donnybrook, each of the railway, and on Grange, Leinster, Kildare, etc., west of the latter. Further north white shales are seen on Lovedale, Arnotsdale, Richmond, and Thornhill, between Belmont and Douglas, while a splendid section is obtained on the southern face of Kababas Kop. The thickness of the shales here is about 50 feet; elsewhere it is thinner.

The most northerly point at which this band was clearly recognisable was at the summit of a little conical hill on the farm Stofputs, to the south-west of Kimberley. When freshly exposed the beds are black, and it is very probable that the uppermost portion of the carbonaceous shales at the Kimberley mines represent a portion of the "White-Band," for whitish shales are exposed a little to the west of the Kimberley Mine.

South of the Orange River the White-band is found between Hopetown and Orange River Station, and east of the railway on the farm Elandsdraai. It is succeeded by shales of the Ecca series.

Fossils.—Indistinct impressions of plants are abundant in the shales, while long flattened stems are characteristic of the white-band. A fragment of what appears to be a ***gangamopteris*** was found at Koodoes Berg Drift, on the Riet River, in a shale containing a few glaciated boulders.

The "white-band" of the Herbert Division has yielded specimens of the small reptile *Mesosaurus*, but unfortunately the exact localities cannot be identified. The remains obtained by Gervais† came from a point north of the Orange River.

Gürich‡ obtained fragments of a form which he named *Ditrochosaurus* (probably a young *Mesosaurus*), both from the Kimberley Mine and from a point on the railway just north of the Orange River Bridge.

The specimens described by Seeley†† came (1) from the Albania Field-cornetcy of Herbert; (2) as inclusions in the blue-

† P. Gervais. Mém. de l'Acad. de Montpellier. Sec des. Sc. VI., p. 172, 1865

‡ Gürich. Zeits. de. Deutsch. Geol. Ges. Vol. XLI., p. 641, 1889.

†† Seeley. Quart. Journ. Geol. Soc. Vol. LVIII., p. 586, 1892.

ground of the Kimberley Mine, being derived from strata which had fallen down into the pipe; and (3) from shale a quarter of a mile to the south-east of the Market Square, Kimberley.

From the white-band on the farm Richmond, west of Belmont, a few fragments of shale were obtained, being portions of a cast of a small reptile which Dr. Broom thinks is probably not a *Mesosaurus*.

The reptile *Mesosaurus* seems to be confined to the "white-band," and may be taken as the zone fossil of the uppermost beds of the Dwyka formation. It has been found in Bushmanland|| on the same horizon.

VI. THE ECCA SERIES.

Succeeding the White-band are greenish and bluish shales, which must be classed with the Ecca, but which are seen at only a few places within the area surveyed.

At Kababas Kop about 15 feet of such beds intervene between the white-band and the dolerite, while on the farm Suffolk the conical hill of white shale is crowned with about 10 feet of bluish-green shales.

The shales forming the base of Kols Kop are in great probability of Ecca age.

The main area of Ecca beds lies to the south of Orange River Station, the passage from the Dwyka being considerably obscured by dolerite sills; these beds have not yet been examined.

On the farm Elandsdraai, east of the railway, some fish-scales were found at the base of the formation.

VII. THE INTRUSIVE ROCKS.

A. Intrusions of Pre-Karroo Age.—A little to the west of Barkly is a sill of diabase which has been intruded parallel to the bedding planes of the volcanic rocks, and consequently dips towards the east.

In thin section (1562) under the microscope it is found to consist of large green fibrous hornblendes (uralite), derived from augite, a core of the latter mineral appearing in a few of the crystals. Original brown hornblende occurs as a border to the uralite. There are three varieties of felspar—a considerable amount of clouded, almost opaque, felspar, probably orthoclase, a fresh oligoclase in prisms, and a colourless felspar containing microlites and inclusions, and evidently the last mineral to crystallise. Magnetite is also present.

A dyke of diabase of a very similar type cuts vertically through the volcanics east of Pokwani, and possesses an easterly strike.

|| Broom. Trans. S. A. Phil. Soc., Vol. XV., p. 104, 1904.

In thin section (1559) we find the same intergrowth of brown hornblende and uralite. Magnetite is abundant, and small patches of a micrographic intergrowth of quartz and felspar are also present.

A rather curious rock comes from the shaft of the Kimberley Mine, where it forms a dyke about three feet wide in the quartzites of the Pniel series.

The thin section (1080) shows a medium-grained rock containing pale brownish augite, with, as a rule, idiomorphic outlines. Each augite crystal encloses commonly a pale enstatite, or more generally each crystal of enstatite is flanked by augite. The enstatite is mostly altered to slightly greenish bastite. Biotite is abundant, always in small patches, usually attached to the pyroxenes or to the ilmenite, the latter occurring in crystal plates. All these minerals are enclosed by colourless felspar, which very rarely shows any trace of albite twinning, and is probably orthoclase. A great portion of it is replaced by a colourless fibrous material; probably some kind of zeolite. Quartz is present in small quantity.

The rock, though not showing the typical structure of the vogesite division of the lamprophyre group, approaches that class of rocks most nearly. Mr. Rastall has described a somewhat similar rock, also from the Kimberley Mine.

B. The Karroo Dolerites.—Dolerite dykes are practically absent, and the endless succession of ridges and flat-topped dolerite hills are formed by one single sheet, now much denuded, but at one time continuous over almost this entire area.

At Orange River Station and again east of Belmont, along the Orange River Colony boundary, there are dolerite sheets passing obliquely through the Karroo strata, but with these exceptions only the lowest of the intrusive sheets of the Karroo is here represented.

The sheet is remarkably regular in its mode of occurrence, but in a few places it is split up by one or more layers of shale or sandstone. A good example of this is seen to the north of Windsorton Road Station. As a rule, the strata which at one time existed above the sheet have been altogether removed. There is one notable exception, at Wolvedam, 14 miles west of Kimberley, where a small patch of highly altered sediments still remains capping the dolerite. The shales both above and below the dolerite, more particularly the former, have been intensely altered, and converted into black lydianite and hornstone, while the more arenaceous portions have been changed into prismatic quartzite.

This alteration of shales by the dolerite is very frequent, but the intensity of the induration seems to vary considerably. The Leeuw Berg, east of Douglas, is another good locality where extensive metamorphism can be observed. The dolerite has been intruded entirely in the Karroo shales, and almost invari-

ably at some distance above the base of the Dwyka formation. This distance varies from about 400 feet down to 100 feet. As a rule, however, the intrusion occurs on a horizon not far below the "White-Band" of the Dwyka, sometimes a little above it. Now the base of the Karroo formation, as already shown, varies considerably in altitude from point to point; the dolerite sheet tends to follow these variations of level—at least, the major undulations. For example, considering a section from Windsorton Road westwards towards the Kaap, we first of all find the dolerite extending nearly horizontally. Towards the west it rises slightly, but from the Vaal across to the Harts valley the sheet has been removed by denudation from the great ridge of diabase which forms the watershed between those two rivers.

Near the Frank Smith mine the Dwyka and dolerite come in again with a marked westerly dip; at the Harts River they are both horizontal; from the river up to Boetsap the dolerite rises, and its easterly inclination becomes great enough to prove that in former times its extension must have taken place westwards in the midst of the Dwyka shales which once overlay the limestones of the Kaap.

Thus we find a variation in altitude of at least 500 feet occurring within a distance of a few miles.

A similar rapid variation in altitude corresponding to that of the Karroo floor is well seen along the Kimberley-Schmidt's Drift-road, between the 18th and 26th milestones. So regular is this rising and falling of the base of the dolerite that it seems possible that in places where the Karroo floor is entirely hidden its principal undulations may be inferred from those of the dolerite at the surface.

When this is tested we find that the dolerites dip towards certain axes which run in a north-easterly direction, and therefore more or less parallel to the depressions along the Vaal and Harts Rivers, in which the Dwyka formation was deposited. Such "ridges" and "troughs," if we may so term them, are very well seen in the neighbourhood of Belmont, as well as in several other localities. As an extremely good example we may take the Kimberley group of mines, and it will be seen the base of the dolerite rises and falls according to the altitude of the diabase.

From the De Beers mine the diabase ridge can be "traced" underground in a south-westerly direction. From the railway the dolerite dips away to the north-west and south-east, and the pre-Karroo rocks emerge on the Riet River, disappearing further down stream.

At Wolvedam, where the full section is seen, the sheet has a thickness of about 250 feet, but elsewhere the capping of dolerite does not exceed 100 to 200 feet.

Where denudation has been considerable the hills are flat-topped, and consist principally of shale, with a thin cap of

dolerite, *e.g.*, Vet Berg, Kababas Kop, the ridge on which Moller's Pile is situated, etc. Where the country becomes flatter and the underlying shales have been protected from active erosion the dolerite forms an undulating surface, and on the flats it may decompose to a friable yellowish material, which is frequently concealed by a layer of calcareous tufa. Such a type of country is found around Kimberley, near Secretaris, Riverton Road, Belmont, etc. Excellent supplies of water are obtained from the dolerite in such cases, especially if there is any large area occupied by it. The rock is full of fissures due to the weathering of the material along the joints; this can be very well seen in the open workings of the Kimberley and De Beers mines.

It is a remarkable thing that throughout the area of some 5,000 square miles over which this sheet has been traced there are practically no feeders visible until we approach the Orange River. Some of the molten material must have travelled a considerable distance along the plane of parting in the shales in order to have reached its present position.

Along the Harts River, between Rutlands Drift and Greef Dale, there is a sheet of dolerite which dips westwards below the Kaap; it was probably an important feeder. Further up the valley are a few other minor sills.

The rock forming the great sheet in this area is the usual coarse-grained ophitic dolerite, which may or may not contain olivine. Good petrological accounts of this sheet, as it occurs at Kimberley, have been given by different observers under the various names of dolerite, " basalt," and " olivine-diabase "; there is, therefore, no necessity for any further description.

Later Intrusions of Dolerite.—At Kimberley two small intrusions were noticed which cut through the horizontal sheet of dolerite. The first of these is seen along the road to the Dutoitspan mine, close to the siding which leads to the Power Station. It is about 10 feet in width.

The second is exposed in a trench along the Schmidt's Drift road, almost at its junction with the road to Koodoo's Berg Drift. Both of these intrusions are fine-grained dolerites.

VIII. THE SUPERFICIAL DEPOSITS.

Over wide areas the rocks are concealed by red sand, calcareous-tufa, or gravels, and this is especially true of the lower-lying tracts underlain by the shales of the Dwyka formation. Although some of these deposits, *e.g.*, the high-level gravels and calcareous tufa terraces, must have a considerable antiquity, it is impossible to classify the superficial deposits according to their age, since sand and calcareous tufa are in process of formation at the present day exactly as has been the case in the past. The deposits will thus have to be described according to their lithological characters.

(1) *Sand.*—The sand, so abundant in certain parts of this area, is entirely absent from others, and we may in consequence divide the country into two portions, one of which is sandy, while the other is not.

Sand is absent on the right side of the Harts-Vaal River, but on the left side there is a pronounced sandy belt extending from the river as far as the foot of the diabase ridge forming the eastern side of the valley.

Again, on the left side of the Vaal River sand predominates, with the exception of a small area north of Riverton Road; again, to the south-west of Kimberley almost the whole of the area between the Vaal River and the Orange River Colony boundary is spread with a thick mantle of reddish sand. These flats of sand support a long coarse grass, while in many places large thorn trees flourish, but throughout this area the country has been greatly denuded of its arboreal vegetation.

On the Native Reserve, between Pudimoe and Taungs Stations, there are wide stretches of mealie-fields, showing that much of this red sandy soil has a considerable value from an agricultural standpoint.

Bare tracts of sand and sand dunes are rare, and are confined to the angles formed by the meeting of two rivers, *e.g.*, the junction of Harts, Riet, Vaal, and Orange Rivers.

The sand is often of a deep red colour, almost like brickdust, but upon approaching an area in which calcareous tufa predominates the colour is seldom so intense.

An examination of the material under the microscope shows that the grains are more or less rounded, especially those of quartz, and vary in diameter from a quarter to one millimeter in diameter. The red colour is due to a coating of oxide of iron, which is removed by boiling with hydrochloric acid.

The great bulk of the material is composed of quartz grains, which show trains of inclusions and cavities. Plagioclase felspar is not uncommon, and is present in the form of cleavage flakes, with the angles somewhat worn. Chalcedony and agate are rather rare; zircon and magnetite are abundant, while epidote is a common constituent.

The composition of the sand shows that it has not been derived from the disintegration of the rocks of the district alone. The felspar and magnetite have been contributed by the disintegration of the dolerites, but considering the great area occupied by amygdaloidal diabase, it is most surprising that grains of chalcedony and agate are so rare. The Dwyka shales are too fine-grained to have contributed much, while sandstones are not sufficiently abundant to account for the enormous quantities of sand.

It seems most probable that the quartz-grains have been brought down from the Transvaal by the Harts and Vaal Rivers, and from the Orange River Colony, Cape Colony, and Basutoland by the Orange River.

The sand being deposited along the river banks, will be blown out over the country by the prevailing north-westerly wind. The decomposition of the diabase and dolerite and of the pyrites in the shales yield compounds of iron, which can be taken into solution and deposited as oxide in the cracks and cleavages of the sand grains and around the grains themselves.

A most remarkable phenomenon is the strong bleaching effect which pans have on the colour of the sand. For example, at the salt-pan of Herbert great quantities of bright red sand are blown into the pan from the north-west. In a very short time this sand is bleached, and ultimately it is blown out of the pan and is piled up as a dune of drab-coloured sand on its south-east side.

The sand grains have lost their coating of iron oxide and acquired one of carbonate of lime instead; the magnetite remains unchanged. The bleaching cannot be due to the action of organic acids, for the pans always contain an abundance of carbonate of lime. The sand loses a portion only of its colour in pans which hold fresh-water; the action does not seem to be so complete as in salt-pans, and this makes it very probable that the bleaching is dependant upon a small amount of salt in the water. The presence of a small amount of organic matter may also assist in the removal of the oxide of iron.

In places this covering of red sand attains a thickness of over 10 feet, but its depth is very variable, and it is usually underlain by calcareous tufa.

(2) *Calcareous tufa.*—This material commonly forms beneath the red sand, and wherever the covering is thin it crops out in a series of little hard knobs of most irregular shape. It covers wide areas of the glacial deposits and shales, and its presence at the surface is most frequently an indication of the existence of the Dwyka series below ground. Sometimes it overlies decomposed dolerite, more rarely the Pniel diabase, and it is abundant both on the plateau of the Kaap and on the flats at the foot of the escarpment.

Leaving out of consideration the area west of the Harts-Vaal River, we find that the tufa has almost invariably been formed by the rising to the surface of water charged with carbonate and the deposition of the dissolved matter consequent upon evaporation. The carbonates have been derived from the underlying formations. The Dwyka boulder-beds and shales are invariably calcareous, and, as we have seen, contain thin limestones and calcareous concretions; the dolerites also upon decomposition furnish a large amount of carbonate.

After rain the moisture is drawn to the surface, and the dissolved material deposited either as a layer or in irregular masses in the cracks and fissures of the rocks at the surface. In the case of the shales the joints form channels for the ascent of the

solution, and carbonates are deposited both along these joints and along the planes of bedding (see Fig. 5). The volume of the rock is increased, and the shales are buckled up and contorted at the surface; deeper down the beds are undisturbed. In time the whole of the surface layer of shale has been permeated with calcareous material and increased in volume, and a thick bed of tufa results; upon close examination small fragments of shale are almost sure to be discovered. The same is the case with the Dwyka boulder-beds; the rock is broken up by veins of carbonate, and finally a bed of tufa is formed in which lie boulders derived from the disintegrated glacial material. This explains the large areas of calcareous tufa, the surface of which is strewn with boulders, sometimes striated, and often foreign to the district.

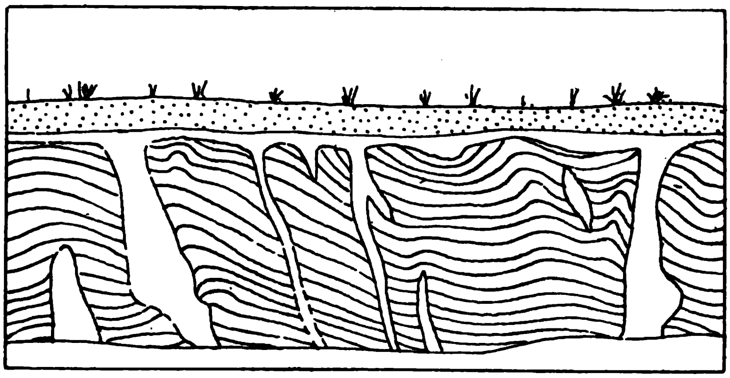

FIG. 5.—Showing the fissuring and contortion of shales through the formation of veins of calcareous tufa when a layer of the latter is produced below the thin covering of red sand. Length of section 12 feet. On railway half a mile north of Kimberley Station.

From Fig. 5 it is seen that the carbonate is brought up to the surface and deposited in the form of a more or less continuous bed below a layer of red sand.

With a thin covering of sand the bed of tufa grows at a nearly constant rate, and acquires a uniform thickness. It is thus forced to raise the layer of sand above it during its growth.

When the depth of sand is more than a few feet there is a differential growth of the tufa (see Figs. 6 and 7). Consider any single upward projection of the surface of the tufa. This is nearer the surface of the ground, and in consequence the capillary attraction will be so much greater. As a result, a larger amount of moisture will be evaporated from the surface of this little protuberance, and it will tend to grow at a greater rate than the rest of the deposit. It grows upwards and outwards, with an outline sometimes resembling that of a mushroom. Its

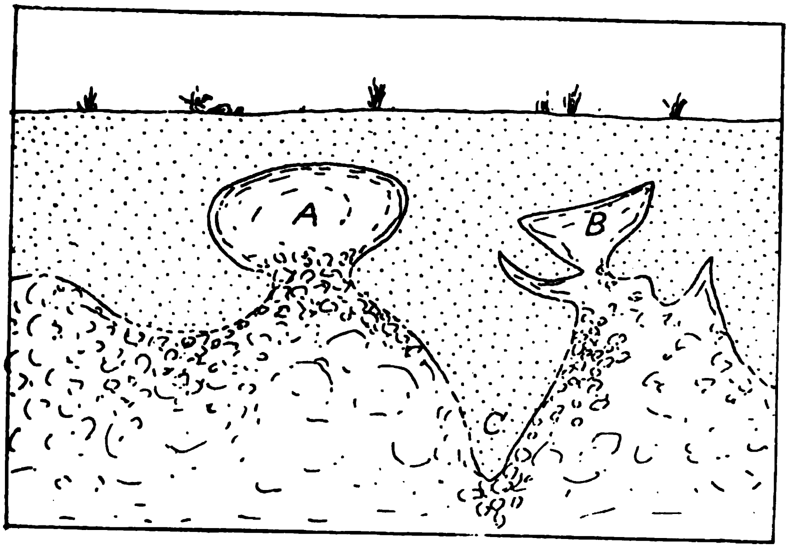

FIG. 6.—Showing the formation and differential growth of calcareous tufa below a thick cover of red sand. Length of section 10 feet. Cutting at the Phœnix Mine, north of Kimberley

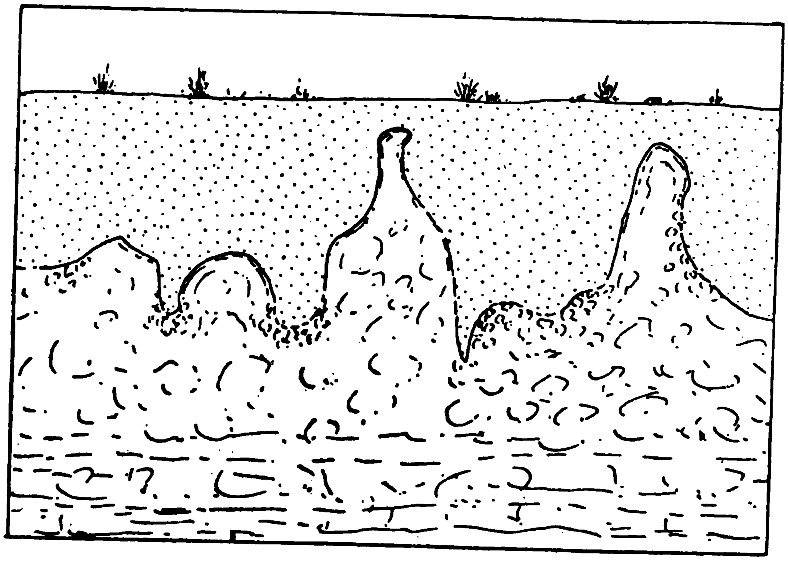

FIG. 7.—Showing the formation and differential growth of calcareous tufa below deep red sand. The tufa passes downwards into a rudely stratified deposit. Length of section 15 feet. Cutting at the Phœnix Mine.

upper surface becomes hard, and upon being fractured the rock shows a somewhat banded structure, with flesh-coloured siliceous zones, and includes numerous little quartz grains. The base of such a hard growth is formed of more or less detached lumps of carbonate, but further down these lumps are bound together and the rock becomes more massive; ultimately it passes into normal rudely stratified tufa.

During the formation of the tufa most of the overlying material is pushed out, and the tufa envelopes only quartz-grains and small pebbles. At Klipdam, where tufa forms below the gravels in such places where the latter overlie the Dwyka formation, the limestone pushes out the earth and retains the pebbles. Sometimes pockets of earth and gravels are found in the tufa, but this is caused by the enlargement of two or more mushroom-like masses and their ultimate union. The initiation of such a process is seen in Fig. 6, and finally the contents of the hollow at C will be enveloped by the continued growth of A and B.

The tufa commonly has a thickness of from 5 to 20 feet, but at Pokwani Station a well 80 feet deep had not reached the solid rock. In a borehole at the same place sandstone was struck at 78 feet. The section showed two layers of tufa 30 feet and 32 feet thick respectively, separated by 10 feet of gravel. These deposits occur immediately opposite a kloof in the ridge to the east, and this probably explains their abnormal thickness.

Another variety of tufa is that which is found overlying the decomposed yellow ground of the diamondiferous pipes and fissures. It has a peculiar greenish-grey appearance, rather difficult to describe, but unmistakeable after having once been seen. The colour is due to small fragments of olivine, enstatite, etc., converted into a yellowish green serpentine. Occasionally the rock has a peculiar scoriaceous appearance, very much like that of a trachytic lava. The tufa passes downwards into the decomosing yellow-ground. Analyses of this variety of tufa are given by Cohen,* and these show that it contains a small amount of magnesium carbonate and a good deal of material insoluble in acid. Cohen† believed that the tufa had been deposited from brackish water during a depression in the Pleistocene Period, but there can be no doubt that Moulle and others were right in considering the material to have been formed in the same way as the tufa elsewhere, the calcareous matter having been derived from the decomposition of the yellow-ground.

On the plateau of the Kaap the rocks are hidden over wide distances by tufa, most of which has been derived by solution from the underlying limestones and dolomites. The thick deposits along the shallow stream-courses indicate that a certain amount of calcareous matter has also been brought down by running water.

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* Cohen. Neues. Jahrb. f. Min., etc., 1887, p. 270.

† *Ibid.* p. 271.

At Boetsap the Dwyka shales abut against the limestones of the Kaap, and the two formations are cut flat and are capped by a continuous sheet of tufa from 20 to 30 feet in thickness. This is the only locality along the edge of the Kaap where the shales rise high enough to form the easterly extension of the Plateau..

A small outlier of shales capped with tufa constitutes the "Fossil Hill," about 100 yards from the main road to Boetsap. The tufa here includes thin, impersistent, and more or less horizontal bands of fibrous stalagmite, in which lie fragments of bone. Many years ago the skeleton of a large animal was found at this spot, but nearly all the bones have been taken away by visitors.

Along the edge of the Kaap there are many springs, which bring to the surface large quantities of calcareous matter. In this way big, irregular masses of tufa have formed high up on the cliffs, while the slope extending eastwards towards the river are covered with a thick deposit, crowded with fragments of limestone, dolomite, flagstone, chert, shale, etc. This slope supports a thick growth of thorn-bushes.

Mr. Young‡ has given analyses of tufa from this belt of country.

The numerous little springs which issue at the base of the escarpment are probably due to the abutting of the less permeable Dwyka shales against a face of water-bearing dolomite. The water issuing disappears again within a short distance into the porous tufa, and there can be no doubt that the underground water resources of the Harts-Vaal River valley must be considerable.

Large springs issue from the dolomite, the water being brought to the surface by layers of hard impervious shale and flagstone. A splendid example of this is the spring known as Thabaseek, to the south-west of Taungs Station.

Terraces covered with calcareous tufa are found on the lower portion of the Riet River and on the Orange River at Hopetown; these represent plains of river erosion. The former is well seen on the farms Abraham Moos Fontein and Taaibosch Fontein, and has an altitude of from 70 to 120 feet above the river bed. The terrace at Hopetown is finely developed, and the tufa is about 30 feet thick. At the town it is 140 feet above the level of the river, and away from it it rises with a slope of about one in a hundred.

The tufa in each case is crowded with water-worn pebbles.

(3) *Pan-deposits.*—The floors of pans are formed by a reddish or greyish-black friable soil, sometimes rather argillaceous in character. Round the edges of pans there is not uncommonly a deposit of tufa, which contains remains of mollusca, *e.g.*, ***Pupa***, ***Succinea***, etc.

‡ Trans. Geol. Soc. S. A., Vol. IX., p. 58, 1906.

At Roode Pan (Hayfield) there is a deposit of *diatomite* with a thickness of at least several feet. This material is probably not uncommon around pans, but is so easily mistaken for tufa.

(4) *Alluvium.*—Tracts occupied by alluvium are not very extensive. At Douglas there is a considerable area, which is irrigated from the Vaal River by means of a furrow. At the junction with the Riet and Vaal Rivers a large tract has also been put under irrigation.

At the junction of the Riet and Modder Rivers there is a wide alluvial flat, triangular in area, but unfortunately its agricultural possibilities have not been developed.

The big bends of the Harts, Riet, and Vaal Rivers enclose wide tracts of fertile land, of which up to the present but little use has been made.

IX. ON PANS.

Pans are very numerous in this area, and several are of large size, yet this is but the western side of that belt of country dotted with pans which extends along the western border of the Orange River Colony.

In this area the great majority of the pans have been produced by the stripping off of a covering of Dwyka conglomerate or shale from an uneven surface of diabase; in some cases the shales only have been removed, the conglomerate being so much harder, and conforming in outline to the underlying floor. In all cases the excavation has been accomplished principally by the action of the prevailing north-westerly and westerly winds.

As examples of pans determined by a simple hummock of diabase on one side we have Tweeling and Kokuming pans along the Transvaal border, east of Pokwani; that on Langleg, south-east of Riverton; Rust-en-Vrede and Grass Pan, west of Kimberley. As examples in which the pan is almost surrounded by diabase may be cited that on Zoutpans Fontein, near Riverton Road, and the pan 6 miles north-east of that station. All the large pans of Kimberley and Herbert have been formed in shales, below which the diabase forms a depression or basin. Thus we have the Rooi Pan (2 miles across), Vogelstruis Pan, Brak Pan, the pans at Paarde Berg East and Theron's mine, in the western part of Kimberley, and Rooi Pan (Craigie-Burn), Saltpan, Roode Pan (Hayfield), in Herbert. Other pans are surrounded by shales, and the diabase is not exposed in their vicinity, *e.g.*, pan north of Kimberley, Alexandersfontein, Klokfontein, Sluitels Dam, etc.

In a few cases erosion has cut through a thin horizontal capping of dolerite and exposed the softer shales below, thus producing a pan, as, for example, on the farm Brechin, north-east of Hopetown. The complete removal of the rim of dolerite will leave a pan in a flat of shale, and this probably represents the

mode of formation of most of the pans situated upon shale flats bounded by dolerite hills. Such pans are located upon the Dwyka and Ecca shales.

As examples may be cited the pan on Leinster, north-east of Hopetown; Graspan, near the station of that name; Vaal Pan, south-west of Kimberley. It is very probable that the pans north of Kimberley, Alexandersfontein, etc.. are of similar origin. Pans located upon dolerite are not common; there is one good example about 5 miles south of Warrenton, while another is Klip Pan (Burgher's Pan, according to Stow), near Graspan Station; a third is Dutoitspan. Sometimes a pan is located on the junction of shale with an inclined sheet of dolerite.

Swinks Pan, north-east of Belmont, is enclosed by a chain of dolerite hills produced by a sheet of dolerite dipping in all directions away from the pan. Denudation of the crown of this dolerite dome has exposed the shales and determined the position of the pan.

Production of pans by wind erosion.—As an excellent example we may take the Herbert Saltpan, of which a plan is given in Fig. 8; it has also been briefly described by Stow.† The depression is from 20 to 25 feet in depth, and nearly a mile in diameter; on the north and west the rim is very steep, while on the south and east are two curved lines of sand dunes. The red sand, which is blown in on the north and west, is rapidly bleached and ejected on the south and west, together with a certain amount of finely divided calcareous material. The loose sand forming the sand dunes is fixed by short grasses; deeper down it becomes compacted through the infiltration of calcareous material.

Similar sand hills are found on the east side of Roode Pan (Hayfield), but there are no clearly defined dunes. The large pan about midway between Kimberley and the pumping-station at Riverton has hills of loose sand on its south-east side.

At Klip Pan, where the pan is excavated in decomposed friable dolerite, the ridge to the east is formed of an accumulation of tiny fragments of dolerite cemented by tufa.

Owing to the deep sandy soil around most pans, very little material, and that only the finest sand, is carried down into the depression even during heavy rains. The pan soon dries up and the thin film of mud breaks up at first into fragments and afterwards into fine dust, which is readily removed by the action of the wind. Many pans are thus being deepened at the present day, but there is good reason to believe that certain pans are being silted up. This may be due either to the invasion of the

† G. W. Stow. Quart. Journ. Geol. Soc., Vol. XXX., p. 589, 1873.

area by large quantities of drift sand or to the disturbance brought about by human occupation. Roads and ditches cut in the sides of the pan enable streams to discharge a large amount of sediment into the pan and thus silt it up. I was informed that many years ago the Herbert Saltpan had a fringe of tall reeds and grasses, while the country round about was thickly grassed; thus the discharge of sediment-laden water into the pan was to a great degree prevented.

Salt pans.—Owing to the influx of water into pans and its ultimate evaporation, there is always the tendency for pans to become salt.

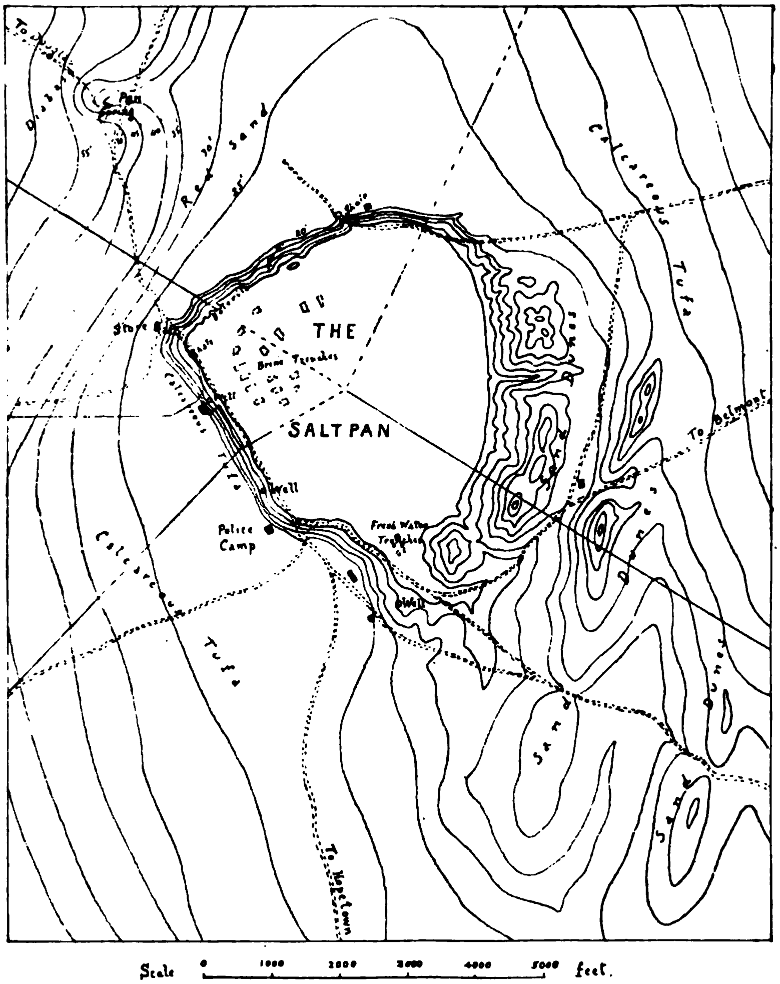

Fig. 8—Plan of the Herbert Salt Pan. Contour lines at intervals of five feet.

At Theron's Mine the water from the pan contains, I am told, a certain amount of sodic nitrate, but all the other "brack-pans" yield common salt only; gypsum appears to be absent.

There are several pans in which the amount of saline matter is sufficient to justify its recovery. Thus, we have salt-works at Riverton Road, Klokfontein, and the Herbert Saltpan, while the Jacobsdal Saltpan is just across the border, close to Honeynest Kloof Station.

Wells and boreholes sunk in the Dwyka formation in the north and west of the Colony frequently yield salt water. The saline constituents are not disseminated evenly through the rocks, and it not uncommonly happens that of two wells a short distance apart, one produces fresh water while the other yields brine. As an example may be cited a small basin filled in with shales, a little to the east of the Leicester Mine. A well here produced brine, while, not 200 feet away, an enormous supply of fresh water is obtained and utilised in washing the diamondiferous gravels.

Seeing that many pans have been eroded out of shales, and are underlain by a basin-shaped surface of hard impervious diabase, it is probable that water in gravitating towards this depression, has leached out the saline matter in the Dwyka conglomerate and shale, and concentrated it below the floor of the pan. There will thus be produced in the soil a lower denser layer of brine and an upper lighter stratum of fresh water. The demarcation between the two liquids is probably sharp, for after rains the fresh water in pans is found to float above the brine without mixing for a certain period, and the supply of strong brine is not appreciably interfered with by a moderate rainfall.

This will explain why, at the Saltpan, fresh water is obtained from shallow pits round the sides of the pan and even on the gently sloping floor of the pan itself at its southern end.

The amount of salt stored up in these pans and available in the future must be extremely great, and therefore of no small economic importance.

SECTION II.

THE DIAMONDIFEROUS AND ALLIED PIPES AND FISSURES.

I. INTRODUCTORY.

Pipes and fissures filled with the peculiar ultrabasic breccia, appropriately termed *Kimberlite* by Prof. Carvill Lewis, are numerous in the Divisions of Kimberley and Barkly West, and from the additions to their number annually it cannot be doubted that many still await discovery.

Of those which have been located and prospected only a small percentage have proved worthy of exploitation; the remainder may be termed "blank mines." Several of the mines abandoned some years ago are at the present moment being reopened and tested in a more systematic and thorough way. This is in part due to the improvements effected in the treatment of the material, whereby the cost of recovery of the gems is reduced, and in part to the higher prices realised for diamonds during the last few years.

The unique phenomena of the diamond pipes have attracted the attention of mining engineers and geologists from the date of their discovery in 1870, and the interest in them has by no means diminished with time and increased knowledge.

The great bulk of the literature on the subject deals principally with the mines of the Kimberley group, while not much has been written about the outside productive mines, and almost nothing regarding the numerous barren or unremunerative pipes and fissures.

In the succeeding account of the pipes it will, therefore, be unnecessary to give much detail regarding the mines of the Kimberley group, and description will be limited to such points as have been omitted in previous writings or about which there was some degree of uncertainty. This will be followed by a short discussion of pipes and fissures in general, and by a petrological description of material collected from the Kimberlite occurrences.

The following are some of the more important works dealing with the pipes and their contents from a general standpoint; other papers concerning the minerals and rocks associated with them will be referred to later on, while a full list of the literature is given in Miss Wilman's "Catalogue of Books and Papers on South African Geology."*

* Trans. S. A. Phil. Soc., Vol. XV., part 5, 1905.

Bauer, M. Precious Stones (Edelsteinkunde). Translated by L. J. Spencer. London. 1904.
Boutan, E. Diamant. Paris. 1886.
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Dunn, E. J. Quart. Journ. Geol. Soc. Vol. 30. London. 1874.
Launay, L. de. Les diamantes du Cap. Paris. 1897.
Moulle, A. Mémoire, etc. Ann. des Mines. Vol. VII. Paris. 1885.
Reunert, T. The Diamond Mines of South Africa. 1892.
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II. DESCRIPTION OF THE PIPES AND FISSURES.

A. Division of Kimberley.

The Kimberley group consists of eleven pipes arranged according to the plan given in Fig. 9. Several other occurrences of Kimberlite were known in the early days of Kimberley, but the ground on which they occur has been either built over or reserved and almost all knowledge of their positions lost.

Kimberley Mine.—The workings in this mine have attained a depth of over 2,900 feet, and prove that from a depth of 800 feet downwards the cross-sectional area becomes nearly constant.

In section it is oval (Fig. 10*); at a considerable depth a fissure is found to extend westwards from the pipe, and has been followed several hundred yards without terminating; its width varies from 6 to 8 feet.

Taken in conjunction with the fact that the pipe inclines bodily towards the north it is very probable that this offshoot joins up with the St. Augustine's Mine.

Among the inclusions in the "blue-ground" of this mine must be specially mentioned dark quartzites, which, in spite of their bedded nature, are remarkably smoothed and rounded. Peridotites must be extremely rare, for after a prolonged search I obtained only one specimen.

De Beers Mine.—A plan of this mine is given in Fig. 11, and indicates possibly a twin-pipe, more especially as the north-western half contains such poor ground that this portion of the mine has not been found to be worth working. Some of this ground is a hardibank.

* Figs. 10 and 11 are taken from the Annual Report of the Inspector of Mines for 1892.

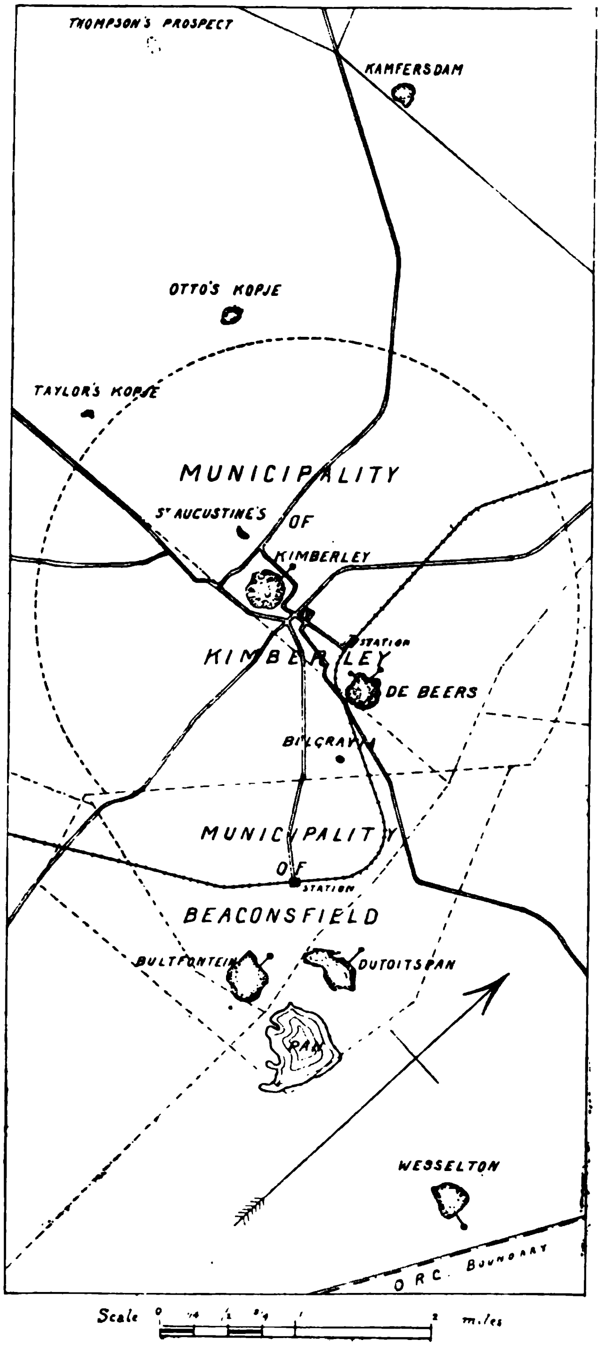


FIG. 9.—Plan showing the positions of the pipes in the neighbourhood of Kimberley.

Fig 10 **PLAN OF KIMBERLEY MINE**

1000 FT LEVEL

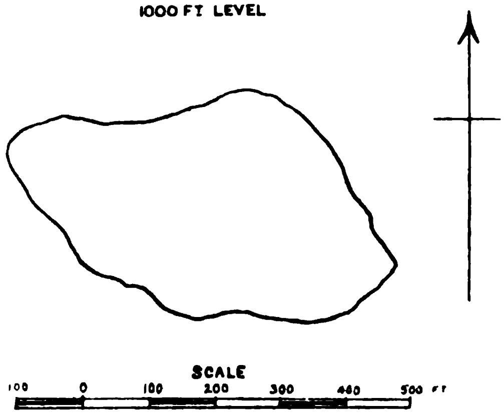
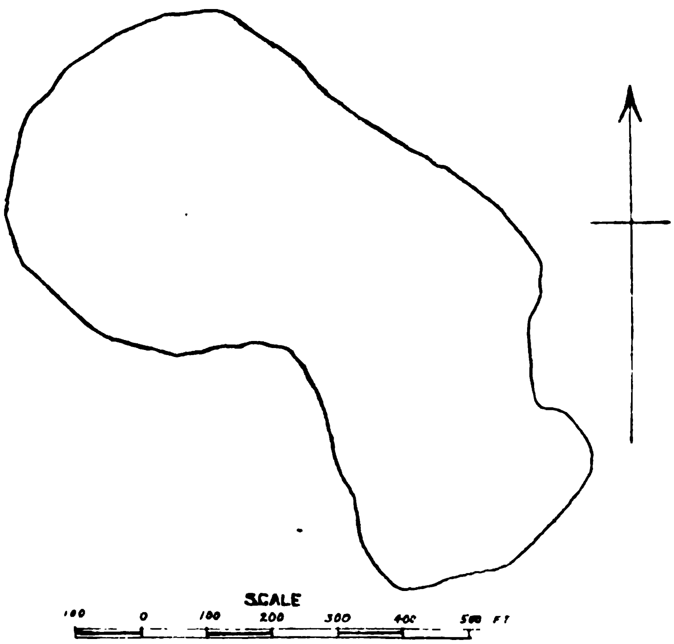


Fig 11 **PLAN OF DE BEERS MINE**

800 FT LEVEL



Considerable interest is attached to certain crooked dykes which traversed the yellow ground, whence the term "snake rock." The dyke rock is sharply defined from the yellow and blue ground, and cuts through the quartz-porphyry at the 1,720 foot level.

Inclusions of actinolite-schist and amphibolite are rather common in this mine.

Dutoitspan.—This mine is elongated with a constriction almost cutting off its western extremity. Much of the yellow ground is crowded with large boulders of dolerite, sandstone, shale, etc, and is often too poor to repay working. At the western end a big mass of hardibank forms a pyramid known as Mount Ararat. At the opposite end of the mine, there is a large dyke-like mass of brecciated dolerite.

The sandstone inclusions cannot be matched in the Dwyka series, and must have been derived from a higher horizon.

Boulders of coarse-grained peridotite are abundant in the blue-ground. Some of the hard blue is very fine-grained, devoid of foreign inclusions, and shows a beautifully vesicular structure, the vesicles being lined with small crystals of calcite.

Bultfontein.—A large area towards the north-west has been left untouched, being too poor to work. Some of this material shows distinct stratification, the bedding planes dipping at a high angle towards the centre of the pipe. On the south side and adhering to the wall of the pipe, there is a great mass of shale-breccia at least 100 feet in thickness, but which does not extend into the lower workings. In it is a block of whitish grey sandstone over 8 feet in diameter, and showing grooves and scratches on its exterior. Portions of the shale are similarly striated. Both the shale and sandstone are not represented among the sediments forming the wall of the pipe.

The most prominent feature in the Bultfontein Mine is a huge mass of brecciated dolerite, passing into a dolerite-shale-breccia, which extends across the pipe from north to south and dips nearly vertically.

Apophyllite and other zeolites have formed in beautiful crystals in the spaces betwen the masses of dolerite, and are accompanied by calcite.

The inclusions in the blue ground are very numerous, and the peridotites are frequently extremely coarse-grained rocks.

Wesselton (*Premier*) *Mine.*—This mine is of interest on account of the inclusions which have been found in the blue-ground.

A block of sandstone containing remains of a fossil fish was obtained at a depth of 135 feet. This was determined by Dr. A. Smith Woodward, of the British Museum, as an *Acrolepis*, a genus known as yet from the Beaufort beds only.

At a depth of 220 feet a large mass of coal was discovered, and the five tons which were taken out were utilised in steam-raising at the mine, the coal proving to be of good quality.

There can be no doubt that both the fossil fish and the coal have been derived from higher strata, which at one time extended over this area and which have since been removed by denudation.

A portion of a carbonised tree trunk was unearthed at a depth of 350 feet, and may possibly have come from the same horizon as the coal.

St. Augustine's Mine.—This mine is situated a short distance to the west of the Kimberley Mine, about 150 yards from Tucker Street.

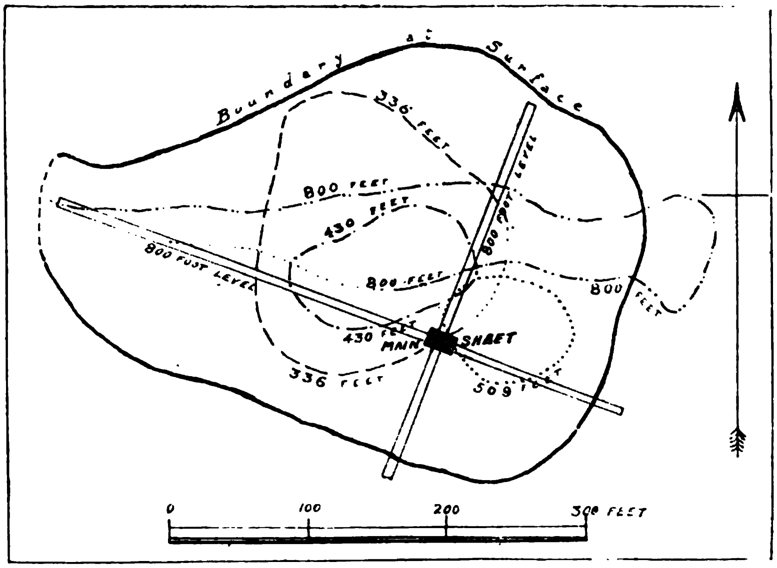


Fig. 12.—Plan of the St. Augustine's Mine, Kimberley, showing the boundaries of the pipe at the different levels.

At the time of my visit the mine was being filled up with debris, and in a short time no trace of its existence will remain.

A shaft was sunk to a depth of 820 feet, and a plan showing the boundary of the pipe at different levels is given in Fig. 12. Upon examining this it will be seen that the pipe varies considerably, not only in shape but in position as the depth increases, and at the 800 foot level it becomes elongated and fissure-like, the whole body of blue dipping northwards at an angle of about 45°.

At the surface the pipe is surrounded by black shales, which dip away on all sides at a considerable angle. At 800 feet the drives were in the hard quartzite of the Pniel series, the quartzite being struck at a depth of 751 feet.

Nearly all the yellow ground was worked out, and many small diamonds recovered, but the hard-blue was met at a depth of 70 feet, and would not weather upon exposure.

The hard blue of the St. Augustine's Mine is quite unique, and is distinct from that of any other occurrence known to me. It is extremely hard and of a slatey blue colour; the mineral constituents are much larger than usual, attaining a size of an inch across occasionally. These mineral grains are nearly all smoothed and rounded as though water-worn, and often the rock has the appearance either of a conglomerate or of a lava with infilled vesicles.

The grains are not always regular in outline, but they very rarely show any faces and sharp edges; the surfaces are always dull and dark coloured, and they appear rough under the microscope.

They range from less than one-eighth up to an inch in diameter. Olivine, ilmenite, and enstatite are abundant, garnet and diopside rather rare.

Inclusions within the pipe are not abundant, and consist chiefly of shale, quartzite-conglomerate (from the base of the Zoetlief beds), and diabase.

Kamfersdam Mine.—The pipe is situated about four miles to the north-west of Kimberley. The portion worked is nearly circular in outline, and is surrounded by shales. On the south-east side there are two dyke-like masses of hardibank. One of these crops out at the surface, and can be followed across the fence into the farm Vooruitzigt, where it has a width of about 30 yards. It is hard and brownish in colour at the surface, but below ground in a shaft it changes to dark green. It contains large decomposed olivines and is almost devoid of any foreign inclusions; it passes insensibly into normal yellow or blue ground.

To the south-east the hardibank is replaced by soft yellow ground, and forms an area at least 200 feet wide and 500 yards in length.

The pipe may, therefore, be regarded as rather elongated, with a constriction (filled with hardibank), while its north-western extremity is circular in outline.

The Kamfersdam pipe is interesting as showing the effect of heat upon the shales at the contact with the yellow ground. This is well seen at the north-western edge of the pipe. The shales have been tilted by the intrusive kimberlite and lenticular portions included by the latter, the shale being baked to a hard flinty material (lydianite). Fragments of similarly altered rock are included in the hardibank.

On the west side of the mine the shales dip towards the pipe, a marked exception to the general tilting away of the strata.

On the north side of the mine, at a short distance down, was a horizontally lying wedge-shaped mass of a peculiar breccia

or pseudo-conglomerate. The rock composing it is light grey in colour, and consists of fragments of soft shaley mudstone set in a similar groundmass and containing neither yellow ground nor foreign boulders.

The fragments vary from angular to sub-angular; generally the corners and edges have been worn off and sometimes the faces are finely scratched and striated. The rock evidently represents a mass of brecciated and crushed shaly mudstone.

The blue ground is characterised by an abundance of fragments of black shales and well-rounded boulders of dolerite, usually so large as to require blasting before removal.

The diamonds won are said to be, as a rule, small and of inferior quality.

Otto's Kopje.—This mine is situated about two and a half miles to the north-west of Kimberley. After having been worked for some time the mine was closed down, but lately some development work has been undertaken, and there is some hope of it being re-opened.

In outline the pipe much resembles Kamfersdam. Thus the portion worked is rudely circular, or more correctly, somewhat elliptical. It exhibits a similar constriction and then expands into an elongated pipe, whose boundaries have not been exactly determined.

The longer axis of the pipe, unlike that of Kamfersdam, is directed towards the south-west.

The diamonds are said to be of good quality.

Taylor's Kopje lies a little to the south, almost in line with Kamfersdam and Otto's Kopje. This mine was abandoned many years ago. The blue ground is interesting petrologically, and the shale fragments show the action of heat very clearly.

There are several other abandoned mines in the neighbourhood of Kimberley, *e.g.*, the *Belgravia* within the town, and *Thompson's Prospect* north-west of Otto's Kopje. Moulle* notes also a pipe known as *Doyle's Kopje*, somewhere to the north of the Kimberley pipe, and probably included in the area covered by the "floors" attached to that mine. It was of interest on account of the large inclusions of granite which occurred in the ground.

North of Kimberley are several pipes which are not being worked at the present time, *e.g.*, the *Pole* and *Phœnix Mines*, between Dronfield and Riverton Road Stations, and also one on the farm Zoutpans Fontein, about half a mile from the Vaal River.

South of Kimberley, at Wimbledon Siding, are two oval-shaped pipes, one about 250 feet and the other about 300 feet in length. They are surrounded by dolerite, but the shale underlying is exposed in some of the inclines. The inclusions in the

* A. Moulle, p. 73.

yellow ground consist of granite and gneiss, amphibolite, gabbro, peridotite, diabase, dolerite, rhyolite, flagstones, shales, etc.

Theron's Mine or Kimberley West is situated on the farm Roode Pan, about 27½ miles to the west-south-west of Kimberley.

The pipe is on the eastern side of the pan, and occupies quite a considerable portion of the pan itself; its exact boundaries in this direction have not been determined, and it appears to have an irregular outline. The country rock has been laid bare on the north side, and proves the pipe to be funnel-shaped. The strata dip away and the rock surface is smooth and shows vertical striations.

The most noticeable feature in this mine is the clear evidence which it shows of the high temperature of its contents at the instant of their intrusion. The soft Dwyka shales forming the walls of the pipe have been baked into a hard flinty material, and the gradual increase of metamorphism as the pipe is approached can be well studied in a long incline on the south-east side of the mine. The zone of alteration extends for a considerable distance and is quite as marked as in the case of many dolerite intrusions.

Large masses of "floating-reef" have been altered throughout; in many places the beds have been shattered and penetrated by numerous tongues and veins of kimberlite, and often the rock passes into a bluish breccia of great hardness.

The yellow-ground does not differ from that of any other mine, and is diamondiferous. Masses of dolerite are present, but the great bulk of the inclusions consist of hardened shale.

Paarde Berg East.—This mine, a few miles to the north-west of Theron's Mine, is in course of development, and its limits at the time of my visit were uncertain. This was in part owing to the great size of the inclusions ("floating-reef") in the yellow ground, requiring a large amount of work before their exact nature could be realised.

Some of these inclusions must have been broken from the sides of the pipe, and have suffered hardly any vertical or horizontal movement, for they are masses of Dwyka horizontally bedded passing downwards from shale into conglomerate and entirely isolated in the yellow ground. The base of the Dwyka formation cannot be deep, for a small hummock of diabase crops out between the mine and the homestead.

In the eastern workings the shales have been converted into hard flinty and quartzitic material.

Both in this and in Theron's Mine the calcareous tufa overlying and adjoining the pipe contains small fragments of ferruginous material, doubtless oxidised pieces of hardened shale.

This is an indication of the proximity of a pipe in which the effect of heat is well marked.

Yellow ground has been located at several other points on this farm, but more work is needed to determine the extent and value of the occurrences.

On *Secretaris*, west of Kimberley, there are several fissures filled with kimberlite, and which trend in different directions; the westernmost one must have a considerable length. Eclogite boulders are common in the eastern fissure.

B. Division of Barkly West.

Immediately to the west of the town of Barkly are the *Russell* and *Victoria Mines*, and in the angle formed by the Vaal and Harts Rivers, the *Washington* and *Borrell's Kopje Mines*.

In the last named, the yellow ground is overlain by from 2 to 3 feet of hard conglomerate containing water-worn river pebbles and that in turn by from 15 to 25 feet of calcareous tufa.

The Newlands Mines.—An excellent description, accompanied by a plan of this group of pipes, has been given by Graichen*, supplementing the full account of the rocks and minerals by Bonney.†

The pipes occur on the farm Newlands (H.V. 42) on the left bank of the Harts River. Dwyka shales form the country rock, and are covered by a thin capping of Karroo dolerite.

The main shaft at No. 2 mine passed through dolerite, black shale, Dwyka conglomerate, "bastard-blue," and, at 250 feet, entered diabase (amygdaloidal, porphyritic, and brecciated), containing a bed of black quartzite, possibly the same bed as that interbedded in the diabases a little to the east of Delport's Hope. Blue ground was struck at 463 feet, and as the pipe opens to the surface at a distance of nearly a hundred feet to the north, it has apparently a deviation of over 10° from the vertical.

There are four small pipes arranged along a nearly straight line, the most interesting feature being their connection with one another below ground by means of a dyke of kimberlite, which varies in width from one up to seven feet. This dyke only rises to the surface in certain places, but its continuity below ground has been proved in the workings. Its strike is nearly north-east.

The blue ground is very hard, and contains numbers of garnets. Inclusions of granite, diabase, dolerite, and eclogite are common.

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* W. Graichen. Zeits. für prakt. Geol., Vol. XI., p. 448, 1903.

† T. G. Bonney. Geol. Magazine, p. 309, 1899

The interest in the Newlands Mines centres in the discovery of small diamonds embedded in boulders of eclogite.‡

The diamonds recovered from the kimberlite, although small, were of a very high quality. The mines were abandoned owing to the hardness of the ground and the small workable body of material.

Smith-Weltevreden Mine.—Further up the Harts Valley in a depression between two dolerite capped ridges, is the pipe commonly known as the Frank Smith Mine.

As indicated in Fig. 13, this is really a twin pipe, the greater portion of which falls within the farm H.V. 37. The area on

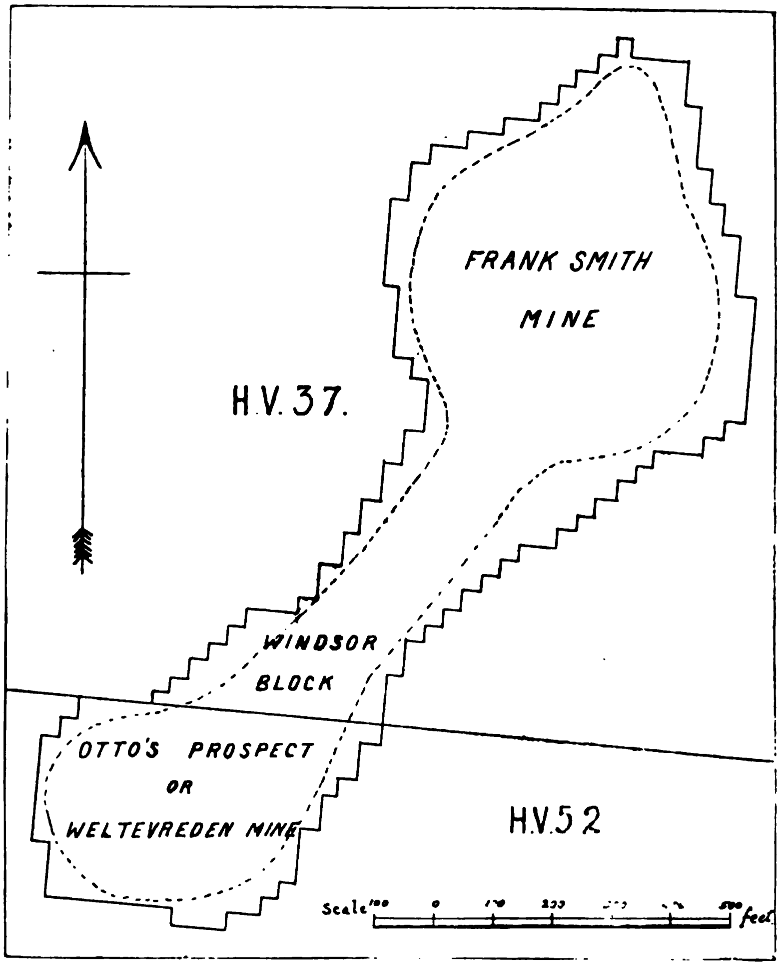

Fig. 13.—Plan of the Smith-Weltevreden Mine.

‡ See above papers, and also R. Beck., Zeits. für prakt. Geol. p. 163, 1898.

H.V. 54 has been worked separately, and is known as Otto's Prospect or the Weltevreden Mine. The narrow neck north of the fence is called the Windsor Block, and the remainder of the pipe, the only part which is being worked at present, is called the Smith Mine.

The neck uniting the two portions of this dumb-bell-shaped pipe enters very sharply into the northern area, and is not more than 150 feet in width. The material filling it is mostly a hardibank, and contains very little so-called yellow ground, nevertheless, curiously enough, this portion of the mine contains large lumps of ilmenite and is rich in diamonds.

Just on the line of the fence there is a large mass of breccia, composed chiefly of red and purple basaltic lavas, the amygdales being filled with calcite and zeolites. Lithologically they have a great resemblance to the Stormberg lavas of Cape Colony.

In thin section (1567-9) under the microscope the rocks prove to be olivine-basalts. The felspar (labradorite) is slightly altered, but the augite is quite fresh, and the two minerals mutually interfere.

Olivine is in small idiomorphic crystals altered sometimes to a brownish laminated or fibrous pleochroic mineral resembling iddingsite, but more usually to greenish serpentine. The groundmass consists of a dark brownish glass containing microlites and granules of iron ores. It is often rendered opaque through the presence of ferric oxide..

Tnese fragments of lava have either fallen into the pipe from above or else have been derived from a mass of molten material in the pipe and which is either slightly earlier than or contemporaneous with the intrusion of the kimberlite.

With each of these views there are difficulties, and it is impossible to decide which is the more likely.

Sapphire and rubies were reported by Prof. Lawn from this mine, but it seems probable that there is some mistake in the identification, especially in view of the fact that fragments of a garnet-cyanite rock have been obtained from the blue-ground.

Leicester Mine.—This is situated on the farm Eland's Drift, a couple of miles to the south of Klipdam. It penetrates diabase, Dwyka conglomerate (the latter being about 3 feet thick) and shales. Being located in one of the basin-shaped hollows in the diabase the mine makes a great deal of water.

The Balmoral or Jubilee Mine, a small cylindrical pipe, penetrates diabase about three-quarters of a mile to the north-east of the Leicester.

Wrigley's Kopje is much larger, and is a short distance further on.

The diamonds from the Leicester, Balmoral, and Newlands Mines, and perhaps also Wrigley's Kopje, are said to be finer in quality than those of any other mine excepting Jagersfontein.

Several small mines lie to the south of Klipdam, others to the north, *e.g.*, Cyrus Mine (H.V. 11). On Llanover (H.V. 61) there is a long fissure extending westwards on to H.V. 30, while several pipes have been located in the neighbourhood.

III. THE PHENOMENA OF THE PIPES AND FISSURES.

(1) *Distribution.*—In the earlier days it was generally believed that there was a well-defined narrow area—the "Diamond Belt"—to which the pipes were confined.

In 1896 we find Bauer, following Penning,* upholding the theory that all the mines from the Newlands to Jagersfontein are arranged at points along a nearly straight fissure,† while as late as 1903 we have an advocate of this view in Graichen,‡ in spite of the fact that the Newlands group of dykes and swellings which he describes extend almost at right angles to this direction. Every day shows more and more the erratic distribution of the occurrences of Kimberlite; pipes may occur in groups or be arranged along more or less straight lines, but considered as a whole, they show no regularity of distribution.

(2) *Shape and contour.*—Between the extremes of Kimberlite occurrences—*pipes and fissures*—there are all connecting links; those which, though dyke-like, expand at one or more points may for convenience be termed "*fissure-swellings.*"

Balmoral and Jagersfontein are examples of pipes with a more or less circular outline, but the great majority are oval or elongated; some have a small expansion at one end, *e.g.*, Dutoitspan and Otto's Kopje. Pipes such as these can often be regarded as having been produced by the coalescence of two or more distinct chimneys, and as a fine example of this may be cited the dumb-bell-shaped Smith-Weltevreden mine.

The section of every pipe shows variations in contour at different depths, and sometimes there are remarkable changes within comparatively short distances. For example, in the De Beers Mine a variation of one hundred feet horizontally has been known to take place within a vertical range of about twenty feet. The walls of most pipes show in consequence hollows and protuberances, which may affect in no small degree the area of workable ground.

A bodily deflection of the pipe is not uncommon, as previously mentioned; another good example is the Kaalfontein mine of the Transvaal.** As an extreme case we have the St. Augustine's mine at Kimberley. According to old plans, the pipes of the Kimberley group after emerging from the hard diabase ex-

* W. H. Penning. Gold and Diamonds, p. 6. 1901.
† M. Bauer. Precious Stones, p. 212.
‡ W. Graichen. Zeits. für prakt. Geol., p. 448. 1903.
** Kynaston and Hall. Rept. S. A. A. A. Sc. for 1903, p. 191.

panded considerably, thus forming a funnel-shaped throat. Moulle || states that the sides of the Kimberley mine were inclined to the central axis at an angle of about 15°. This feature appears to be due, firstly, to the easier shattering and disintegration of the soft shales, and, secondly, to the rending action due to the subsequent expansion of the altering Kimberlite.

Below the Karroo rocks the cross-sections diminish a little at first, and ultimately acquire a nearly constant area.

The intimate connection between pipes and fissures, so well seen in the St. Augustine's mine, receives ample confirmation from the study of other occurrences, and it may, I think, be put down almost as a generalisation, that every pipe has some important dyke-like off-shoot, if not at the surface, at some greater depth.

In the Newlands group the pipes are connected below ground by a narrow dyke of Kimberlite; on Secretaris, west of Kimberley, we have fissures with one or more little swellings on them, and thus finally we arrive at the numerous class of Kimberlite "dykes and veins," which vary in width from belts many feet across to mere stringers.

The direction of some of these fissures is often probably connected with the jointing in the hard rocks which they penetrate, *e.g.*, Newlands, Smith, and Peiser mines (Hay), which have a north-easterly strike parallel to that of the surrounding pre-Karroo formations.

(3) *Contents of the pipes and fissures.*—The inclusions found at any particular locality in a pipe may have been derived (*a*) from above, (*b*) from the sides of the pipe, or (*c*) from below.

(*a*) There can be no doubt that in times past the pipes extended upwards through strata higher than those which now exist in the neighbourhood. Mr. Harger¶ has laid special stress upon this point.

The evidences for this upward extension are drawn firstly from the inclusions within the pipes, and secondly from the great amount of denudation which has taken place in Central South Africa since Jurassic times.

The inclusions of the Wesselton mine afford convincing evidence, while in the Premier mine of the Transvaal†† there are great masses of Waterberg conglomerate, though the base of the latter formation is only seen *in situ* some miles away. Small fragments of Karroo shale have been carried down to great depths, and are an abundant constituent of the blue-ground in the lowest workings of the Kimberley mine, *i.e.*, over 2,000 feet below the base of the Karroo formation.

(*b*) Many of the large masses of "floating-reef" appear to have been broken from the walls of the pipe during a late stage

|| A. Moulle. p. 57.
¶ H. Harger. Trans. Geol. Soc. S. A., Vol. VIII., p. 113-5, 1905.
†† Kynaston and Hall. Rept. Geol. Surv. Transvaal for 1903, p. 44.

in the eruption, and to have suffered but little vertical displacement. Such masses, sometimes entire, sometimes brecciated, were abundant in the upper funnel-shaped openings of the mines of the Kimberley group, and have been noticed as well in Paarde Berg East.

(*c*) The great bulk of the material filling the pipes has, of course, come up from below. For example, there are fragments of sedimentary and volcanic rocks from the pre-Karroo formations, granite gneiss and pegmatite, tremolite and actinolite schist and amphibolite. Among the rarer rocks are gabbro (Wimbledon), garnet-cyanite-rock (Frank Smith and Roberts Victor), and glaucophane rock (Peiser).

In the pipe at Silver Dam (Sutherland), which is allied to those at Kimberley, are granulites of various types related to the eclogites, while lastly we have the extremely varied holocrystalline basic and ultrabasic rocks, composed of different combinations of the minerals olivine, enstatite, chrome-diopside, garnet, mica, and sometimes ilmenite, and which have contributed largely to the formation of Kimberlite.

The most prominent feature in all the inclusions is the remarkable degree of rounding which they exhibit; it is therefore not surprising that Prof. Bonney‡‡ should have come to the conclusion that the eclogite boulders in the Newlands mine had been derived from true water-formed conglomerates. The dolerite boulders are commonly in large rounded masses; the ultrabasic inclusions sometimes attain a length of two feet, and show pitted surfaces owing to the decomposition of the crystals of olivine; the eclogites have invariably smooth, sometimes polished, surfaces. The blocks of quartzite have their corners worn off, and the only rocks which do not show the effects of attrition are the shales and fissile quartzites. Even the mineral fragments are frequently rounded, but some of this smoothing may be due to other causes.

There is abundant evidence to prove that there has been a great deal of oscillation of the eruptive material—"cup and ball action"—with consequent rounding of the rock inclusions.

In certain places the "blue-ground" is crowded with foreign fragments, and passes into the material commonly known as "bastard-blue." It does not differ essentially from ordinary blue, and may contain diamonds; more usually it refuses to weather, and forms a hardibank.

On the other hand, there are certain portions of the "blue-ground" which are remarkably free from inclusions; they are met with either as lumps or patches (the so-called "concretions"), as veins cutting the blue, or as narrow dykes in the country rock.

(4) *Temperature of the eruptive material.*—There are two opinions generally held as to the temperature that existed in the

‡‡ T. G. Bonney. Geol. Mag., p. 320, 1899.

pipes: one that the "blue" is the product of cold volcanic action, the other that the material was erupted in a highly heated condition.

Luzi's experiments* apparently establishing the corrosive action of molten "blue" on the diamond have been widely quoted as proving a low temperature for the formation of Kimberlite.

The experiments have little value in this connection, for the following reasons:—

(*a*) The blue-ground differs both chemically and mineralogically from the original eruptive matter.

(*b*) From the description of the experiments it is quite possible that the corrosion may have been due to oxygen contained in the melted rock.

(*c*) Even assuming that the molten blue can attack and dissolve the diamond, it certainly does not follow that the reverse process cannot take place.

The effects of high temperature are well seen in the Kimberley West and Paarde Berg East mines, and to a lesser degree in Kamfersdam. In most mines, however, the effects of metamorphism are by no means well recorded—nevertheless, fragments of shale frequently show signs of alteration. Under the microscope such fragments exhibit numerous pale yellow garnets of extremely small dimensions, accompanied by a biotite mica in minute flakes.

In hand specimens many inclusions show zoning to a greater or lesser degree; such changes may, however, be due in part to hydrothermal action.

The effect of heat is indicated by the occurrence of fire-damp in the blue-ground at its contact with the walls of the pipe,† due to the distillation of masses of black shale. The aromatic hydrocarbons extracted from the blue-ground by Sir H. Roscoe have evidently originated in the same way.

On the other hand, many mines exhibit no signs of the action of heat, *e.g.*, the Wesselton mine.

The evidence, apparently conflicting, can, I think, be reconciled by supposing that the Kimberlite magma, at one time in a highly heated state, became chilled during its ascent in the pipe, so that different mines might record the effects of the material at different stages in its cooling.

The Kimberlite dykes of the United States have produced considerable metamorphism both in the country rock and in the inclusions.‡

(5) *The Genesis of Kimberlite.*—It would be useless to discuss the numerous hypotheses to account for the formation of the diamondiferous blue-ground.

* W. Luzi. Ueber künstliche Corrosionsfiguren am Diamanten. Berichte der Deutschen Chemischen Gesellschaft XXV., p. 2470, 1892. Quoted by Gardner Williams.

† A. Moulle. p. 58.; also Ann. Rept. Inspector of Mines for 1895, p. 13.

‡ Carvill Lewis. Genesis and Matrix of the Diamond, pp. 60 and 63, 1897.

The theory which, I venture to think, seems to accord best with the facts may be put briefly as follows:—*That Kimberlite has been produced by the shattering of various holocrystalline basic and ultra-basic rocks and the incorporation of this material by a magma of ultra-basic character.* In its ascent the eruptive material has become cooled and brecciated, and has included in its body fragments of the rocks through which it has passed.

The minerals and mineral fragments in Kimberlite may be divided into three groups according to their source:—

(*a*) Tremolite, smaragdite†† (hornblende), epidote, orthite, tourmaline, rutile, muscovite and biotite mica, apatite, wollastonite (?), and zircon. These have evidently been derived from granite, gneiss, pegmatite, and actinolite schists, and probably also from inclusions in the granite.

Zircon is so abundant (*e.g.*, at the Kimberley mine and Smith mine) that it may possibly have been derived from certain of the basic or ultra-basic rocks.

(*b*) Olivine, enstatite, chrome-diopside, garnet, brown mica, occasionally ilmenite, magnetite and chromite, more rarely hornblende, spinel (picotite, pleonaste, etc.), sphene, cyanite, sapphire, graphite, and the diamond.

These minerals have probably been derived from the basic and ultra-basic holocrystalline rocks—rocks which are often well foliated, and exhibit mineral banding, and which both in hand specimens and under the microscope not infrequently show the effects of dynamic metamorphism. They vary in texture from medium to coarse-grained, and there are sometimes pegmatites. The coarser-grained the rock the more friable it is, and with the pegmatites the portions found are usually fragments of the constituent minerals.

These rocks are mostly deficient in alumina, and hence the rarity of cyanite and spinel.

Owing to the allotriomorphic structure of the parent rocks, the derived fragments in the blue-ground commonly possess angular outlines; the shattering of the material will account also for the frequent discovery of fractured diamonds. The garnets, on the other hand, having originally more or less rounded outlines, tend to break out entire, while the formation of kelyphite rims produces beautifully smooth garnets—"buckshot garnets."

The most noticeable feature in this list of minerals is the absence of perofskite and the very infrequent occurrence of iron ores.

(*c*) Olivine, diopside, enstatite (?), brown mica, magnetite, ilmenite, chromite (?), apatite, perofskite, nepheline, and melilite.

From the evidence set forth below it seems that these min-

†† The smaragdite of Maskelyne and Flight appears from its analysis to be a green actinolitic hornblende with a trace of chromic oxide: a similar amphibole has been recorded from certain diorites.

erals can with a certain degree of probability be ascribed to a deep-seated eruptive magma—which crystallised during its ascent in the pipes, and incorporated in its mass the groups of minerals *a* and *b*.

The Kimberlite of Cape Colony is characterised by the presence of porphyritic olivines, a fact which led Carvill Lewis to term the rock a brecciated porphyritic peridotite. The olivines have very often beautifully regular crystal-outlines, sometimes they are perfectly round, at other times they exhibit corrosion cavities.

Some of this mineral in the blue must be derived from the holocrystalline series, for irregular fragments of olivine are found showing cataclastic structure (1532), or the olivine granules are interlocking (1533); they enclose enstatite (1501, 1508, 1555), or are themselves enclosed by diopside (1079, 1100).

Some of the enstatite can undoubtedly be referred to the holocrystalline series; fragments show intergrowths with diopside (1100, 1518), or include biotite (1501), and sometimes they exexhibit strain shadows. Occasionally the mineral passes into a bronzite, and carries abundant minute platy inclusions of ferric oxide. A small amount of the enstatite possesses idiomorphic outlines, and may therefore be one of the minerals which has separated from the magma.

Diopside is not uncommonly idiomorphic (especially in slide 1077), and judging from the abundance of this mineral in some varieties of Kimberlite, it must in great part have been derived from the magma. The diopside of the holocrystalline rocks has usually a greener tint; some of the chromiferous varieties are feebly pleochroic.

Ilmenite and magnetite are abundant, and perhaps indicate the deep-seated origin of the magma. The blue-ground is crowded with little crystals of perofskite, which frequently show cores of ilmenite and sometimes, though less commonly, of sphene; not infrequently grains of ilmenite are surrounded by a shell of a colourless, highly refracting and weakly polarising material, which seems to be also perofskite. The great bulk of the perofskite may therefore have arisen by the alteration of the titanic iron, as suggested by Carvill Lewis. Some of the ilmenite contains about 12 per cent. of magnesia.†

Nepheline has as yet only been recognised in some Kimberlite from the Monastery mine in the Orange River Colony.‡

Melilite has been found in the melilite-basalt of Sutherland†† in pipes which contain the same assemblage of rocks and minerals as the Kimberley ones. Carvill Lewis suggested that melilite was possibly present originally in the groundmass of Kimberlite, though now altered beyond recognition.

† E. Cohen. Neues Jahrbuch, 695, 1877. Stuttgart.
‡ A. Lacroix. Bull. Soc. Minér., Vol. XXI., p. 22, 1898. Paris.
†† Ann. Rep. Geol. Comm. for 1903, p. 43.

A study of sections (1501, 1077, 1548) of the purer varieties of Kimberlite convinces me that the original uprising igneous material may be classed as a *limburgite*. These purer portions range from large lumps down to fragments of microscopic dimensions, and are embedded in the brecciated and tuff-like masses of the pipes.

In the limburgite of slide 1077 the glassy base has been replaced by serpentine, but in 1548 there remains colourless isotropic material after treatment with strong acids. Although basic or ultra-basic glass would in most cases be altered to serpentine, its existence in the melilite-basalts and glassy vesicular lavas of the Sutherland Commonage pipes shows that such a change does not always take place. In support of this we sometimes find enclosures of brown glass in the olivine phenocrysts. The limburgite of slide 1077 has a very strong resemblance to melilite-basalt, especially through the presence of abundant perofskite and of mica. It is to be regretted that no analysis has been made of this rock.

In the breaking-up of the partially crystallised magma during the formation of Kimberlite the crystals derived from the former and now embedded in the blue-ground not infrequently still show an adhering film of the groundmass in which they originally crystallised (1501, 1099). The same thing has been noticed in a specimen from one of the melilite-basalt pipes.

It is of interest in advancing this theory to find an almost exact parallel from a pipe in Bohemia.|| The pipe is filled with a basaltic breccia containing fragments of various rocks which have been brought up from below. From this tuff almost every one of the minerals characteristic of Kimberlite have been obtained, some of which are derived from the basalt and the remainder from granite, granulite, gneiss, schists, lherzolite, and other inclusions.

Assuming that a highly-heated magma has incorporated in itself fragments of holocrystalline rocks, it would at first sight be expected that there ought to have been a considerable amount of reaction between the magma and the inclusions. Roozeboom¶ has, however, shown that at great depths, such as those at which we may suppose the holocrystalline rocks to be situated, the solubility of silicates is very much less than under normal pressures. Again, Zirkel** has found that at low temperatures basic inclusions are not dissolved by a basic magma. Moreover, olivine has been proved to be scarcely acted upon by basic magmas generally.

In consequence it will follow that the reactions in any case would be slight; in addition, both the magma and the inclusions

|| I. H. Oemichen. Zeits. für prakt. Geol., p. 10, 1900.
¶ C. Doelter. Petrogenesis, p. 121, 1906.
** F. Zirkel. Petrographie, Vol. I., p. 600, 1893.

possess almost the same basicity, and thus there might be practically no interaction.

Thin rims of brown mica sometimes wholly or partially surround some of the minerals, especially the garnet, but as this feature is noticeable in the holocrystalline rocks, the presence of a zone of mica is no safe indication of reaction. The peculiar pegmatitic zones around the enstatite recorded by Carvill Lewis†† were not noticed in the slides of the Survey collection. Possibly the structures were fragments of the holocrystalline rocks.

The brown mica often shows a resorption border of black "opacite," while the crystals have usually been considerably corroded and rounded.

There can be no doubt that the magma has risen from a great depth, from a horizon either within or below the zone of holocrystalline ultra-basic rocks. It would be out of place to discuss the mechanism of the pipes, but several interesting points might be briefly touched upon. The great density of the magma would readily account for the great number of inclusions, especially of heavy ultra-basic rocks, a fact which will also explain why peridotite boulders are so rare as inclusions in more acid lavas, that is, if we except the "olivine-knollen" of certain basalts as fragments of pre-existing rock. The intrusive mass would become crowded with foreign fragments, and the rapid cooling and movement would produce a brecciated structure.

The breaking-up of the holocrystalline rocks would be more complete in the large pipes, for churning movements would take place on a much larger scale than in the small pipes and fissures. This would explain why such large lumps of garnet, ilmenite, chrome-diopside, mica, etc., are found in the "blue-ground" fissures and so rarely in the larger pipes. Perhaps, too, this may account for the scarcity or complete absence of the diamond in the smaller pipes and fissures.

(6) *Alteration of Kimberlite.*—The changes which have affected Kimberlite to a greater or lesser degree, and which are less pronounced in hardibanks, may be viewed from two aspects:—

(*a*) Chemical and mineralogical changes.
(*b*) Mechanical changes.

(*a*) The alteration of the various minerals has been recorded by numerous observers, the most complete account being that by Carvill Lewis. It is sufficient, therefore, merely to note that the olivine and enstatite have become partly or wholly hydrated with the formation of serpentine, while the diopside has given serpentine and a very little calcite. Carvill Lewis regarded the calcite as being possibly largely due to the alteration of melilite; this may or may not be the case.

†† Carvill Lewis. *loc. cit.* p. 18.

Various zeolites have been formed, chief among which are natrolite and apophyllite. Barytes is often a constituent, while pyrites has crystallised in the blue-ground, and is accompanied by nodules of marcasite. At the surface the yellow-ground has completely decomposed into a pale yellowish-green rock seamed with veins of calcite, and sometimes carrying a small amount of opaline silica and oxide of iron.

(*b*) The mechanical effects depend upon the increase in bulk of the breccia due to the partial or complete serpentinization of the olivines, etc. The increase in volume accompanying the alteration of olivine is roughly 30 per cent., that of enstatite 18 per cent., and that of diopside 37 per cent.

Carvill Lewis estimated that about one-half of Kimberlite consists of serpentine (more accurately 45 per cent.); from an analysis given in Rosenbusch‡‡ the proportion is 46 per cent. In certain varieties this figure will not be quite so high.

Assuming a value of 45 per cent. and an average co-efficient of expansion of 30 per cent., the increase in bulk of the material in passing into the stage which we know as blue-ground will be therefore 13½ per cent. Now, the material is confined by walls of hard rock, and the chief way in which relief will take place will be in an upward direction. In consequence the extension of a column of the material will be about 13½ per cent., representing an upward movement of 135 feet per thousand feet. Even assuming that the mass expands equally in all directions, the longitudinal extension of a column will be 4½ per cent. It is reasonable to suppose that the degree of serpentinization will diminish with depth, but, nevertheless, the vertical movement in a column several thousands of feet in height must be considerable.

This explains a unique feature in the Kimberlite occurrences, namely, the turning up of the strata along the edges of pipes or fissures. In all other volcanic necks the strata almost invariably dip towards the axis of the pipe.

The friction between the country rock and the gradually expanding body of Kimberlite is shown by more or less vertical striations and groovings on the walls of the pipes; sheets of calcite formed at the junction frequently show casts of the slickensides.

Owing to differences in the degree of serpentinization, the contents of the pipes have suffered differential expansion, a brecciated structure has been produced, and the blue-ground is traversed by numerous slips and surfaces of shear. It is even possible that a mine may become separated into distinct compartments, each characterised by a different kind of " blue " and each extending vertically downwards. According to Moulle,*

‡‡ H. Rosenbusch. Elemente der Gesteinlehre, 2nd edition, p. 169, Stuttgart, 1901.

* A. Moulle. p. 62.

the Kimberley mine was divided into 15 distinct compartments, separated from one another by narrow " greasy slips," while the existence of poor or barren portions of the blue extending vertically downwards to unknown depths lends further support to this view.

In passing through the Karroo shales large masses seem to have been wedged off from the walls by the expanding material while the Kimberlite has been forced into cracks and joints in the strata.

In the case of dykes which have solidified underground it is even possible that during alteration a certain amount of expansion has taken place upwards, and that the dyke has forced its way through soft strata for a certain distance long after volcanic action had ceased.

A most remarkable property of the blue-ground is its tendency to crumble and pulverise after having been exposed to the weather for a short period. Some portions refuse to disintegrate, and have been given the name of ' hardibank." As yet no one has been able to give any explanation as to the cause of the remarkable differences between the two varieties of Kimberlite. It is certainly true that in hardibanks the constituent minerals are often in an extremely fresh state; nevertheless, the groundmass has been entirely converted into serpentine.

(7) *The Diamond.*—Diamonds have been found crystallised in the garnets of an eclogite from the Newlands mine,† as well as in single garnets from Jagersfontein and the Driekopjes‡ and from the Wesselton mine, while it has also been found embedded in olivine.†† It is interesting to note that the chrome-diopside of an eclogite from Jagersfontein included some foliated graphite.‡‡

So far the only rock which has actually been proved to contain the diamond as an original constituent in South Africa is eclogite. At Kimberley Mr. Gardner Williams had about 20 tons of peridotite boulders crushed and jigged, but no diamonds were recovered. Eclogites are almost unrepresented at Kimberley, and the boulders must have been almost entirely lherzolites. Although this can hardly be considered conclusive, it tends to support the view that the diamond is not a constituent of a lherzolite. Neither is the presence of diamond embedded in olivine decisive, for on the hypothesis which I have advanced the olivines may have been formed from the ultra-basic magma around a crystal of diamond derived from a shattered eclogite.

The high proportion of pipes and fissures in which the diamond is either extremely rare or else absent altogether shows that the parent rock of the diamond is very sparingly and un-

† T. G. Bonney. Geol. Magazine, p. 301, 1899.
‡ H. Harger. Trans. Geol. Soc. S. A., Vol. VIII., p. 133, 1906.
†† Gardner F. Williams in "Science in South Africa," p. 329, 1905.
‡‡ H. Harger. *loc. cit.*, p. 131.

evenly distributed in the earth's crust. Since in nearly all these mines boulders of lherzolite or other variety of peridotite are commonly to be found, we have a further support to the view that the diamond has not crystallised in an olivine-bearing rock.

The typical eclogite is a dark, heavy rock, composed of garnet and chrome-diopside, together with sometimes a small amount of quartz, cyanite, mica, spinel, and more rarely felspar and the diamond. By the addition of olivine and enstatite it becomes a lherzolite, but such transitional types are not common, and there is a possibility that the eclogite is by no means closely related to the peridotites with which it is found. Firstly, the percentage of silica is so much higher, 53·75 per cent. in the case of a sample from Jagersfontein,¶ while it is deficient in magnesia; in the example just referred to it is just under 10 per cent. The diopside being rich in magnesia, the garnet will have to be a variety poor in magnesia, and not pyrope, such as is present in the lherzolites. The mica, too, is rather different from the usual variety.

Secondly, the occasional presence of cyanite—possibly, too, of corundum (sapphire)—allies it to the granulites, a view strengthened by the various types of granulitic rocks obtained from the Silver Dam pipe of the Sutherland Division.|| The discovery of basic granulitic rocks, some exhibiting points of resemblance to the eclogites, as inclusions in the granite of the Mafeking Division|||, and representing rocks which have been enveloped and metamorphosed by it, suggest a similar manner of origin for the eclogites included in kimberlite, so that the eclogite might be a completely metamorphosed rock. Deep down in the crust of the earth the granite will be succeeded by ultra-basic rocks, and the hornblende of the inclusions will be replaced by a pyroxene.

Of no small interest is the peculiar fact that occasionally diamonds are found which either penetrate or enclose one another. Such cases are rare, but in the collection from the De Beers Mines there are several examples of diamonds, each of which encloses a smaller octahedral stone. In one specimen the faces of the included stone are coated with a film of black crystallised carbon; in another, described by Mr. Gardner Williams,† there was a considerable space between the inner and outer stones, and which was filled with apophyllite. This mineral has probably been derived from without, and has been introduced into the space through a crack. The inner stone is somewhat yellower than the others, and thus of a different quality.

¶ E. Cohen. Neues Jahrbuch, p. 867, 1879. Stuttgart.
|| Ann. Rept. Geol. Comm. for 1903, p. 54, and Trans. S. A. Phil. Soc. Vol. XV. p. 68, 1904.
||| Ann. Rept. Geol. Comm. for 1905, p. 210.
† Science in South Africa, p. 327, 1905.

These examples show that in certain cases the growth of the crystals of diamond has proceeded in two distinct stages; such a phenomenon is not unusual in the process of crystallisation of certain minerals in rocks, *e.g.*, zircon.

It is to be hoped that the intergrowths of the diamond with garnet and other minerals will be more closely studied in the future, for one can hardly doubt that much information will be obtained in this way. In addition, more will have to be known about the ultra-basic inclusions of kimberlite, especially in regard to the characters and mode of origin of the eclogites, before the origin of the diamond can be satisfactorily made out.

(8) *Age of the Occurrences.*—That the pipes and fissures are later in age than the Karroo dolerites is clear, and they thus represent the latest phase of volcanic activity in Central South Africa. The dolerites in turn cut the Stormberg lavas, and must be either Jurassic or Lower Cretaceous. If we can correlate the melilite-basalt pipes at Sutherland with a similar intrusion in the Uitenhage (Neocomian) beds at Spiegel River (Heidelberg, C.C.), then the occurrences of kimberlite must be considered of *post-Neocomian* age. This question has been discussed more fully elsewhere.*

IV. PETROLOGICAL DESCRIPTION OF MATERIAL FROM THE PIPES AND FISSURES.

A. Holocrystalline Basic and Ultrabasic inclusions in the Blue-ground.

1525. *Gabbro.—Wimbledon, south of Kimberley.*—Dark coloured rock with blackish-green to bronze-coloured crystals of diallage.

In these sections there are areas of pale greenish diallage set in a fine-grained aggregate of prisms and granules or zoisite with some quartz, calcite and chlorite. The groundmass is evidently a much altered plagioclase felspar (saussurite).

1565. *Garnet-cyanite rock.—Frank Smith Mine.*—In this section, large grains of clear garnet, small crystals of almost colourless cyanite, which seem to be replaced in part by quartz, calcite, and mica. The groundmass consists of a clouded rather indefinite aggregate, probably in great part of colourless felspar and calcite, and which seems to have been produced by the alteration of plagioclase.

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* A. W. Rogers and A. L. du Toit. Trans. S. A. Phil. Soc., Vol. XV, p. 81, 1904.

The rock differs somewhat from the cyanite-garnet rock of the Roberts Victor Mine, described by Prof. R. Beck.*

1572. *Eclogite.—Newlands Mine.*—A medium-grained rock composed of dark blackish green pyroxene and resinous-looking garnet, sp. gravity, 3·23.

The thin section shows pale greenish almost colourless diopside, which has altered in places to a fibrous product probably an amphibole. The garnets are large, full of cracks, and somewhat dusty.

Biotite mica is present in the spaces between the two minerals and is intergrown with the diopside and ramifies in little veins through the garnet. It is a rather unusual variety, having a pleochroism from brownish green and pinkish to colourless.

There are a few little granules of iron ore and a little calcite.

1536. *Eclogite.—Bultfontein Mine.*—A very handsome rock, composed of bright green diopside, pink garnet, and dark mica. Sp. gr., 3·25.

In thin section shows pale green diopside, altered in certain places to greenish serpentine which encloses rhombs of calcite. Cracked pink garnets and a biotite which is intergrown with the diopside and garnet.

1561. ——— *From a fissure near Llanover (H.V. 61), Barkly West.*—A dull blackish rock with spangles of black mica. Sp. gr., 3·05.

The thin section shows this rock to be of a most unusual type. The augite is in beautifully idiomorphic crystals sometimes very much elongated. It is pale in colour and towards the ends of the prisms it passes insensibly into deep green aegerine; this is sometimes also the case along the prism faces.

The augite is altered in a patchy manner to a fibrous product, which in turn has changed to serpentine and calcite. The aegerine forms small crystals in addition, and both these and the large augites are bordered by a fringe of needles and narrow prisms of brownish-green acmite arranged either normally to the crystal faces or more commonly making a small angle with them. Bunches of these acmite prisms are scattered through the groundmass, and are here and there enclosed by a yellowish green mineral which has optical properties similar to those of acmite except in its weaker pleochroism. It is probably a closely related mineral.

Deep reddish-brown biotite is abundant in large plates, and commonly encloses fairly big crystals of apatite. The biotite must have been one of the first minerals to crystallise as the augite has been moulded upon it.

* Proc. Geol. Soc. S. A., p. xlviii., 1906

The colourless groundmass consists of a mixture of quartz and unstriated felspar which, from the presence of aegerine and acmite is probably an orthoclase. The groundmass is crowded with tufts and needles of acmite, abundant large granules and aggregates of sphene, some ilmenite, and crystals of a colourless mineral with high refractive index and negative double refraction.

The rock shows a great resemblance to the theralites, but nepheline could not be recognised with certainty; the abundance of aegerine and acmite, however, indicate a high soda content. From its structure it may possibly be grouped with the camptonites.

1529. *Mica rock.—Taylor's Kopje, Kimberley.*—A well-foliated rock composed almost wholly of a yellow brown mica with weak pleochroism and with a small biaxial angle. Embedded in the mica are small diopsides, seldom showing any crystal edges, and a few grains of sphene.

1539. *Mica rock.—Bultfontein Mine.*—Yellow brown mica with reverse pleochroism, thus differing from the preceding rock. A few grains of diopside and some magnetite. Sp. gr., 2·80.

The rock has been affected by pressure, and is traversed by lines of serpentinous material; the mica crystals are bent, and show an extremely well-developed brachypinacoidal cleavage.

1554. *Enstatite-mica-diopside rock.—Kimberley Mine.*—A well-foliated rock traversed by planes rich in mica.

There are numbers of small diopside grains which are usually enclosed by enstatite or mica; sometimes there is an intergrowth of mica and diopside.

The enstatite shows along edges and cleavage cracks an alteration to bastite and serpentine, while the diopside is in places altered to diallage.

There are two varieties of mica: one a darker yellow brown mica with normal pleochroism which commonly occurs in small hexagonal flakes, and the other a lighter coloured mica with reverse pleochroism which forms large plates having ragged outlines.

Frequently these plates are surrounded by a rim of normal mica; sometimes there is an intergrowth of the two varieties. The mica includes or is attached to sphene and ilmenite.

1517. *Olivine-diopside-mica rock.—De Beers.*—A dark rock traversed by more or less parallel bands rich in mica. Sp. gr., 3·00.

Olivine sometimes in large areas but more commonly in somewhat rounded granules; diopside, which has grown round and enclosed the olivines.

Mica in large plates enclosed both by the olivine and diopside, and showing reverse absorption. In a couple of places it is intergrown with normal mica.

Ilmenite forms small granules enclosed by all the other minerals.

1524. *Olivine-mica rock.—Wimbledon, near Kimberley.*—A dark compact rock with small reddish areas. Sp. gr., 2·86.

In thin section is found to be composed chiefly of olivine, which is capriciously altered, sometimes over large areas to a brownish or greenish serpentine, bluish black along the cracks and cleavages of the mineral. The mica occurs in large aggregates of small plates, and shows reverse absorption and rather weak double refraction.

Included both by the mica and olivine are narrow indefinitely terminated prisms of a colourless mineral, showing a well-defined longitudinal cleavage and an irregular transverse parting. The refractive index is high, double refraction moderate, and the angle of extinction has a maximum value of 30°.

Taken in conjunction with its other optical properties the mineral must be cyanite; its unusual presence in peridotite may perhaps be due to the incorporation of foreign material by an ultra-basic magma.

There are small peculiar ramifying growths of limonite with the mica and cyanite, also a few grains of magnetite.

1540. *Olivine rock.—Bultfontein Mine.*—A black fine-grained rock which can be readily cleaved; shows little patches of mica and small green chrome-diopside grains. Sp. gr., 2·75.

In thin section the great bulk of the rock is found to be composed of olivine. Owing to the extremely crushed nature of the rock the olivine is found to be granulitized, and different parts of what was originally one crystal are now differently oriented. Alteration has proceeded along the cracks, and we thus find a regular mosaic of olivine granules of more or less uniform size set in a groundmass of pale greenish serpentine, in fact the rock shows features very similar to those in a fine-grained quartzite. A crystal of enstatite has been similarly granulitized but the shattering and serpentinization have not been so great. The diopside grains being so small have not been much affected. Minute grains of magnetite are present, almost entirely in the enstatite.

1530. *Olivine-enstatite rock (Saxonite)—Taylor's Kopje, Kimberley.*—A coarse-grained rock composed of olivine and enstatite. The former is in large crystals, and shows a good cleavage and strain shadows; it is only slightly altered along cracks. There is a small amount of pale yellow mica in which are embedded grains of magnetite, and a few small granules of chrome-diopside.

1534. *Olivine-enstatite rock* (*Saxonite*).—*Dutoitspan Mine.*—A dark coarse-grained rock in which the enstatite has a platy structure; towards the exterior of the boulder the bastite cleavage is more strongly developed and the crystals have a reddish metallic appearance. Sp. gr., 2·87.

In thin section the olivine exhibits a remarkably fine cleavage and is altered along cracks and cleavages to yellowish serpentine, which has in places a deep bluish tint. The enstatite has a pale brownish appearance due to the fibrous structure. A few flakes of mica are present. There are peculiar ramifying or graphic intergrowths of limonite with the mica and olivine.

1538. *Olivine-enstatite rock* (*Saxonite*)..—*Bultfontein Mine.*—A coarse-grained rock in which the enstatites are sometimes more than half-an-inch across.

The thin section shows olivine much serpentinized and a very fibrous brown enstatite with a very feeble pleochroism. Like the preceding rock, there are intergrowths of limonite and olivine.

1535. *Olivine-enstatite rock* (*Saxonite*).—*Dutoitspan Mine.*—A dull black rock containing bright platy enstatites sometimes over an inch across.

It is very much like 1538 but contains small biotites, mostly in well-formed hexagonal plates, which are collected along the lines of junction of the enstatite and olivine.

1504. *Olivine-enstatite rock* (*Saxonite*).—*De Beers Mine.*—A very handsome dark green rock with bronze-coloured brilliant enstatite (bronzite) crystals from an eighth to a quarter of an inch across, and from which the mica can only be distinguished with difficulty. Sp. gr., 3·00.

In thin section the most interesting mineral is found to be the enstatite. It is deep yellow-brown in colour except in a few places where it is still quite fresh. The colour is due to minute elongated plates of an iron ore which are arranged along one set of cleavage planes.

One section is cut at rignt angles to the plane containing the inclusions and to the vertical axis of the crystal; the inclusions are thus seen on edge as parallel rows of disconnected lines, and acting on light like a diffraction grating give a blue grey colour to the enstatite instead of a yellow brown.

Pale yellowish feebly pleochroic mica borders the enstatite; one crystal shows a ramifying growth with limonite.

1502. *Olivine-enstatite-garnet rock.*—*De Beers Mine.*—A medium-grained green rock. Sp. gr., 3·19.

Enstatite in elongated crystals with rounded ends and with fibrous serpentinous borders surrounded by olivine. The latter is traversed by lines of crush indicated by bands of granulitic olivine sometimes forming a mosaic. The olivine includes small idiomorphic crystals of a nearly colourless mineral having the optical properties of epidote. A few garnets are represented and are much clouded and almost opaque; seen by reflected light they are dirty-white in colour.

There are several areas of yellowish green serpentine enclosing crystals of a pale biotite, probably of secondary origin.

1516. *Olivine-enstatite-garnet rock.—Bultfontein Mine.*—A deep black rock with greyish crystals of enstatite, small garnets, and little bright green grains of chrome-diopside. Sp. gr., 2·98.

In thin section the only feature worth noting is the dark bluish black zone of colour bordering the serpentine along the cracks of the olivine. The colour is due to the separation of magnetite in a finely-divided form, which acts as a diffraction grating upon the transmitted light.

1506. *Olivine-enstatite-diopside-garnet rock (Lherzolite).—Bultfontein Mine.*—In this rock the grains of the different minerals approach one another more nearly in size than in any of the other holocrystalline rocks described, and thereby a medium-grained granulitic rock is produced. The chrome-diopside has a diallagic habit in places, and is altered along cracks to yellow serpentine.

The serpentine produced from olivine has often, as in 1516, a dark blue colour due to dispersion.

The garnets are dusty and cracked, but rather large, and are distributed irregularly through the rock.

1514. *Enstatite-olivine-diopside-garnet rock (Lherzolite).—De Beers.*—Enstatite very abundant and very fresh; olivine less in quantity than is usual; large garnets which are clear and colourless, and round which some mica has formed. Pale greenish chrome-diopside has formed in the spaces between the other minerals. In one case it shows twinning.

1513. *Enstatite-diopside-olivine-mica rock.—De Beers.*—As indicating the extraordinary variation of the peridotites it may be remarked that this section and the preceding one have been cut from opposite ends of the same hand specimen.

The portion yielding this section is a dark greenish-grey mottled rock through which are distributed aggregates of mica, which contain none of the other minerals of the rock and which have sharply defined outlines. They are circular or oval in section and have a diameter of from one to three eighths of an inch.

In thin section these patches are formed of interlocking plates of a nearly colourless mica commonly enclosing, especially towards their centres, minute crystals of iron ore. The edges of the patches are either bordered with a narrow band of serpentine calcite and small pyroxenes, or else the mica becomes intergrown with the diopside, sometimes ophitically.

The chrome-diopside has a pale yellowish-green tint, and occurs both simple and twinned; commonly the crystals are small and interlocking.

The enstatite and olivine are in rather large crystals.

1537. *Olivine-enstatite-diopside-garnet rock (Lherzolite).—Bultfontein Mine.*—The olivine has been generally much crushed, and polarises frequently as a mosaic. The narrow veins of serpentine which traverse this mineral have often a dull blue colour; under a high power there is seen a narrow central axis from which extends outwards a fringe of dark thread-like bodies formed by rows of minute magnetite granules. These structures may best be likened to the midrib and venation of ferns.

The enstatite is clear but sometimes considerably altered to colourless serpentine. The chrome-diopside is pale yellowish-green in sections, and is much altered along the cleavages similarly; the absence of calcite indicates that the diopside contains no lime.

The garnets are nearly colourless in section; in the hand specimen they are beautifully smooth and often well rounded.

1505. *Olivine-diopside-garnet rock.—Bultfontein Mine.*—A dull green rock with small amethystine garnets. Sp. gr., 2·98.

The olivine is granulitized in certain places.

The diopside is a colourless variety which is intergrown with a little chrome-diopside. A small amount of enstatite is present. Garnets are abundant and are small, well-rounded, and dusty; they have dark borders.

1515. *Olivine-diopside-garnet rock.—Bultfontein Mine.*—A dark green rock with large well-rounded deep red garnets. Sp. gr., 2·90.

Olivine and pale green almost colourless diopside, both much altered to pale serpentine. The garnet and sometimes the diopside is surrounded by a very narrow zone of yellow brown mica, which there is no reason to believe to be other than original.

1507. *Enstatite-diopside-olivine-mica rock.—Bultfontein Mine.*—A greyish rock with plates of brown mica and grains of bright green chrome-diopside. Sp. gr., 3·11.

Enstatite and a colourless diopside form the great bulk of the rock; olivine is not abundant. Pale green very weakly pleochroic chrome-diopside and a yellow mica are present in about

equal proportions. The chrome-diopside and olivine were the first minerals to crystallize and were followed by the mica and the two pyroxenes.

Summary of the characters shown by the Peridotites.—The peridotites consist of different combinations of the minerals olivine, enstatite, diopside, mica, and garnet, and seldom contain more than a very small amount of iron ores. The rather low densities which they possess may be accounted for partly by alterations which have affected the constituent minerals and partly by the small iron content of the rocks. The olivine, enstatite, and diopside are evidently nearly pure magnesian silicates, and through hydration produce nearly colourless serpentine with but a trace of calcite and magnetite. The densities of the minerals will therefore be lower than those of the corresponding ferriferous varieties.

The rocks exhibit even in hand-specimens great variation in composition, while very often they show marked mineral banding and are foliated.

In texture they vary from medium to extremely coarse-grained rocks; the olivines do not attain any great size, but lumps of enstatite and diopside the size of a man's fist are not uncommon in the blue ground, and garnets far bigger even—Graichen mentions one from the Newlands Mine about 12 inches in diameter.

The rocks show the effect of earth-pressure and the olivines are not infrequently granulitized; the enstatite and diopside have not been affected to the same degree. In one specimen (145 l.) a large crystal of enstatite has been sharply folded and is traversed by small thrust-planes.

The source of the peridotites must lie far below the granite. The latter being a well-foliated gneissic variety, it is natural to suppose that the crushing and shearing of the ultra-basic holocrystalline rocks has been accomplished by the same forces which produced the foliation in the granite. It is nevertheless possible that the foliation and mineral-banding in the peridotites are due to causes which operated at a still more remote period in geological history.

B. KIMBERLITE.

Such excellent accounts of the petrological character of the blue-ground have been given by Carvill Lewis and Prof. Bonney that in the following pages only special points in the different varieties of Kimberlite will be noticed. The majority of the sections have been taken from hardibanks on account of the fresher state of the constituent minerals.

1527. *Hard-blue.—Taylor's Kopje, Kimberley.*—Olivine very fresh, often in finely idiomorphic crystals, showing macrodomes and pinacoids; usually serpentinized on the outside the serpentine so formed containing little needles of rutile. The

crystals of olivine in the groundmass are frequently so minute as to give the rock a porphyritic appearance. Mica both normal and abnormal, usually intergrown; borders bleached and possessing rims of opacite. Some diopside. Groundmass of serpentine, ilmenite, perofskite, etc. Inclusions of peridotite and dolerite.

1518. *Hard-blue.—Kimberley Mine.*—Large olivines, diopsides, enstatites, and fragments of peridotite, all with rounded outlines, and which are set in a groundmass crowded with tiny olivines mostly showing crystal outlines. Serpentine, perofskite, ilmenite, etc.

1501. *De Beers Mine.*—A piece of fine-grained blue, traversed by a two-inch vein of coarse-grained rock; in the thin section the junction between these two varieties is very sharp.

The fine-grained rock contains porphyritic olivines and slightly-rounded or else angular pieces of olivine, enstatite, diopside, and corroded micas set in a dense groundmass crowded with granules of iron ore; perofskite is not abundant.

The coarse-grained portion is crowded with fragments of shale, grit, dolerite, peridotite, etc., and includes some finely idiomorphic olivines. That these last have been derived from the fine-grained rock is quite evident, for they are frequently surrounded by a narrow zone of the dark groundmass characteristic of the latter, while angular and rounded portions of the fine-grained rock are abundant The groundmass of the coarse-grained portion is light in colour and rich in calcite.

Clearly the fine-grained rock represents the original magma with its included fragments derived from the deep-seated holocrystalline rocks; through brecciation and the consequent mingling with fragments of shale, etc., the coarse-grained variety, approaching more nearly in character the usual type of Kimberlite, has been produced.

1099. *Soft-blue.—Kimberley.*—The specimen shows somewhat similar features to the preceding rock. Many of the olivines show an attached film of a fine-grained serpentinous material containing ilmenite and perofskite, the whole being enclosed by a ring of dark matter.

1077. *Vein in blue-ground.—1,200 foot level, De Beers Mine.*—An extremely fine-grained rock crowded with finely-idiomorphic little olivines and diopsides which are perfectly fresh and unaltered. The groundmass consists of colourless serpentine, granules of ilmenite and perofskite and a few irregularly-shaped flakes of mica.

The rock was very probably originally a glassy peridotite (*limburgite*), but the glass has now been hydrated with the formation of serpentine and a little calcite; it seems to approach most nearly in character to the "generative-magma" of Kimberlite.

1162. "*Snake rock.*"—*Dyke in porphyry at 1,720 foot level, De Beers Mine.*—Very much like ordinary blue-ground, but the minerals are much less altered. Olivine, enstatite and diopside are abundant, the first named being finely idiomorphic as a rule; mica of both varieties.

Foreign fragments are present, but not abundant.

The "Snake-rock" is a slightly later intrusion, and cuts vertically through the blue-ground of the mine.

1532. *Vein in blue-ground.*—*Dutoitspan Mine.*—Idiomorphic and angular olivine and angular or rounded diopside, enstatite and fragments of peridotite embedded in an extremely dense groundmass.

The olivines are altered along cracks and are surrounded by an inner narrow zone of radially arranged fibrous chrysotile enclosed by a thin shell of colourless serpentine.

A most notable feature in regard to the olivine is the abundance of needles of rutile in it lying in positions more or less parallel to the crystal boundaries. The rutile is as abundant in the unaltered as in the serpentinized portions of the olivines, and is, therefore, not confined to the latter, as believed by Carvill Lewis.†

Micas of both varieties are well represented and are always surrounded by deep black borders.

1548. *Vesicular blue-ground.*—*Dutoitspan Mine.*—A dark blue very fine-grained rock devoid of foreign inclusions and full of cavities lined or filled by calcite. These vesicles are sometimes arranged in rows, and give the rock a banded appearance.

In thin section the minerals of the rock are olivine and diopside with subordinate enstatite and mica, the two first-named being usually idiomorphic. The groundmass contains a good deal of serpentine, rhombohedra of calcite, and abundant little prisms of apatite. By treatment with strong hydrochloric acid these minerals are removed and there remains a pale, almost colourless, isotropic unstainable substance containing minute dark granules, iron ores, perofskite, etc.

† Carvill Lewis. p. 17.

1510, 1511. *Hard blue.—St. Augustine's Mine, Kimberley.* —Olivine very abundant, enstatite and diopside subordinate. The mineral grains are sometimes beautifully rounded, but the olivine has a tendency to idiomorphic outlines. Abundant tiny olivines in the groundmass. The micas are much altered and replaced by aggregates of chlorite, a nearly colourless mica, and carbonates.

1522. *Hard blue.—Wimbledon, near Kimberley.*—The olivine and possibly enstatite and diopside are completely replaced by a perfectly clear and colourless serpentine. Carbonates rarely accompany the latter, but the presence of a small amount of iron is shown by very minute specks of iron oxide.

The groundmass consists of a small amount of serpentine with a large quantity of calcite, and it is crammed with minute micas in well-formed hexagonal plates and with small apatite prisms. The micas show a core of the normal and shell of the abnormal variety. Ilmenite and perofskite are not so abundant as usual.

1543. *Hardibank.—Kamfersdam Mine.*—An interesting feature about this rock is its dark green colour, which is due to plates of a weakly pleochroic chlorite, evidently an altered mica.

Perofskite is most abundant, and in many cases includes a core of titanic iron, sometimes one of sphene. This is not a unique feature confined to this rock alone, but is shown in every slide of kimberlite.

Where the grains of ilmenite are large they are surrounded by a ring of little perofskite crystals. The granules of ilmenite and sphene are frequently surrounded by a shell of highly refractive and weakly polarising mineral which varies from colourless to pale bluish or yellowish; it is commonly enveloped by iron oxide. This mineral seems to be an alteration product of the titanic iron; possibly it is a variety of perofskite, for it is sometimes associated with that mineral and, like it, a single grain is found under polarised light to consist of several individual crystals. This alteration product of ilmenite is abundant in certain varieties of kimberlite.

1555. *Hard blue.—"Mount Ararat," Dutoitspan Mine.*—A rather altered rock with numerous enclosures of shale, diabase, dolerite, and peridotite. The groundmass contains abundant granules of ilmenite altering to the colourless mineral mentioned above. The crystals of the latter are large, show square or hexagonal outlines, and have a rather wide border; granules of perofskite are sometimes frequent in the colourless alteration mineral.

There are numerous narrow lath-shaped areas of calcite which represent pseudomorphs after some unknown mineral, also minute needles of apatite.

C. On an Abnormal Mica.

The presence of a pale magnesian mica with reverse pleochroism has been remarked upon as occurring both in the ultrabasic rocks and in the blue ground. It is so abundant—nearly every other slide of kimberlite containing one or more flakes—that it is extraordinary that it should have hitherto escaped observation and comment.

Except for its action on polarised light this variety does not differ from the normal mica in the blue ground. It is found both in large plates and in minute little scales, and sometimes forms a nearly pure mica rock. *Both* micas sometimes show a remarkably brachypinacoidal cleavage sometimes developed to such a degree that a cleavage flake can be broken up into little rectangular prisms, and in extreme cases the mineral becomes almost fibrous. Both varieties are very nearly uniaxial; the optic axial plane is the plane of symmetry and the mica is of the second order. The extinction angle, measured from the trace of the basal cleavage, has a value from 0° up to 4°. Both micas have a very pale tint, and the pleochroism is from colourless to light yellow brown, but sometimes the change is hardly noticeable. They are probably intermediate between the biotite and phlogopite micas.

In the abnormal mica the maximum absorption occurs when the basal cleavage is at right angles to the short-diagonal of the nicol-prism; in basal sections there is no appreciable change of colour. The absorption scheme is

$$\mathfrak{a} > \mathfrak{b} \lesseqgtr \mathfrak{c}$$

It frequently occurs intergrown with normal mica, and invariably has a lower double-refraction, commonly about two thirds of the value for the latter. In the great majority of cases the normal mica forms a zone around the abnormal variety; in section 1522 this order is reversed and little crystals of normal mica are surrounded by a shell of abnormal, the latter having a more pronounced pleochroism—from brown to a very pale green.

A mica of similar abnormal character was recorded several years ago in melilite-basalt from a pipe on Matjes Fontein (Sutherland),* and constitutes another point of resemblance between the pipes containing melilite-basalt and those filled with kimberlite.

* Ann. Rept. Geol. Comm, for 1903, p. 50.

The micas in the blue-ground have in part been derived from the breaking up of the ultra-basic rocks, the plates being frequently bent or attached to enstatite or some other mineral.

That some of these micas have originated from the magma is shown in several ways. They often occur in little plates with regular hexagonal outlines, and are almost devoid of inclusions. There can be no doubt that the micas of the melilite-basalts have formed out during the crystallisation of those rocks.

In slide 1522 there is a fine example of the regeneration of a fragment of mica derived probably from the shattering of a granite. The core is a bent flake of slightly dusty pleochroic biotite, it is surrounded by a pale normal mica, and that in turn by a shell of the abnormal variety. The growth of micas in the magma can very frequently be inferred by the fact that a ragged core of normal or abnormal mica has had its crystal outline reconstructed, the new material being a nearly colourless variety. Embedded in this shell, usually at the junction of the two varieties, are abundant inclusions of ilmenite, perofskite and apatite, minerals with which the groundmass of the rock is crowded. Some of the crystals with "bleached-borders" may have acquired those characters through a secondary growth of mica.

The abnormal mica is not confined to the blue-ground of the mines described in this Report; I have found it also in material from the Jagersfontein, Premier (Transvaal) and Monastery Mines (O.R.C.), and it is probably widely distributed.

Abnormal biotite mica has been recorded from other parts of the world,† and a slide (1094) in the Survey collection of monchiquite rock from India shows an intergrowth of normal and abnormal biotite.

No analysis was made of this abnormal mica in order to determine whether it differs in chemical composition from the normal variety, but it is somewhat denser, the specific gravities of the two kinds being 2·796 and 2·731 respectively.

† C. Hintze. Handbuch der Mineralogie, II., p. 546.

SECTION III.

THE DIAMONDIFEROUS GRAVELS.

The diamond-bearing gravels of the Vaal River Valley have received a considerable amount of attention by geologists from a very early period, yet practically all our information consists of the somewhat brief descriptions of the "diggings" by Stow, Shaw, Cohen, Moulle, Dunn, Boutan, and Coe.

The gravels occur at intervals on both banks of the Vaal River, sometimes at a considerable distance from the river-bed and usually in more or less disconnected patches. Such gravelly deposits have been worked from Christiana, in the Transvaal, as far south as the junction of the Vaal with the Orange River. Gravels occur as well on the Orange and Riet Rivers, but are sparingly diamondiferous. There are no deposits of this nature in the Harts River Valley

The gravels are situated at various levels as well as at varying distances from the river, and though they form a number of fairly distinct terraces, it is not always easy to determine their relative age.

In order to make clear what follows a brief account of the nistory of the Vaal River will be necessary.

The Vaal River at one time flowed entirely over rocks belonging to the Karroo formation—that is within the area under description. Upon deepening its channel the underlying floor of diabase and amygdaloid was laid bare, and while the river was able to excavate rapidly in certain parts of its course, such as to the north-east of Warrenton, at Riverton, Pniel, Delport's Hope, and from Schmidt's Drift down to beyond Douglas, in other places it had to cut its way through ridges of hard rock. The two most important barriers were between Warrenton and Windsorton, and again between Barkly and Sydney, but there are numerous minor ridges all along the river as well.

On the up-stream side of the barrier the rate of deepening would be far less than on the down-stream side, and hence the gravels deposited at these two points will differ in elevation above the bed of the river.

For example, at Warrenton the gravels cover a wide area between the village and the railway; the surface upon which they are deposited, though rather uneven, slopes gently towards the river, and has an altitude of from 50 to 75 feet above it. The gravels are unevenly distributed over this surface, and, therefore, form a layer of variable thickness. Little patches occur on the north bank close to Fourteen Streams Station.

From Warrenton the gradient of the Vaal increases, and the river flows in a deep gorge cut in diabase. Little patches of gravels still remain on both sides of the river, and as one proceeds down stream their altitude relative to the river-bed increases.

Thus we find areas of high-level gravels on Waterval, Roode Dam, and Hebron, the diggings on this last farm being known as " Fool's Rush."

East of Windsorton the upper gravels are absent owing to the subsequent erosion of the soft Karroo beds. Little patches of gravel and accumulations of pebbles on the flats between Windsorton Road and Riverton Road Stations are probably relics of this terrace.

On the west of the Vaal the terrace is finely developed at Klipdam, where it has an altitude of 200 feet above the river and a distance from it of $3\frac{1}{2}$ to 6 miles. Both the diabase and Dwyka formations have been cut equally to form an even surface falling gradually to the south.

The principal tract of gravels is from a half to one and a half miles in width, and extends southwards from Klipdam for a distance of five miles. Outliers occur to the west and south-west, at Holpan, while lower gravels are being worked south of the Leicester Mine.

The continuation of the Klipdam terrace is found on Modder Hoek, about a mile from the Vaal, and forms a remarkably even slope, extending along the right bank of the river into the bend opposite Riverton. The gravels rest upon Dwyka shales and splendid sections are seen along the cliff facing the river (on Khosop's Kraal). The slope in the twelve miles from Klipdam is at the rate of 10 feet per mile.

It is evident that the Vaal has been able to cut more rapidly downwards here than to the north of Windsorton, so that the gravels at the two extremities of the layer extending from Klipdam to Khosop's Kraal are not of the same age. The Klipdam portion represents the oldest part of the deposit, while that at Khosop's Kraal is of considerably later age. The Warrenton deposits, on the other hand, cover the entire period taken for the formation of the gravel-covered Klipdam-Khosop's Kraal slope.

As the Vaal deepened its course near Windsorton, a lower bank of gravels was deposited some 50 feet or thereabouts above the level of the present river.

This terrace extends for a distance behind the village, both up and down the river, while it appears on the opposite bank, on Rietput, and carries the upper gravels of the Wedburg area. Patches of gravel also occur down stream on Krans Vogel Vlei and in the big bend on Slyp Klip North.

Just as we find a gravel slope stretching from Klipdam to Khosop's Kraal, so we have the same feature repeated just

before reaching Barkly. The highest gravels cap a diabase ridge on Hols Dam; from this point there is an almost unbroken slope into the great loop of the Vaal, opposie Pniel, known as "The Bend."

Little patches of the oldest gravels occur at points about a mile and a half north-west, and again north-east of Barkly, and have an altitude of about 200 feet above the river-bed.

From Barkly to Delport's Hope we have a repetition of the Warrenton-Riverton section; the river has had to cut through a barrier of diabase, but beyond this ridge the soft Karroo rocks have been easily disintegrated and the older gravels removed along with them. Thus none of the deposits from Waldeck's Plant to Delport's Hope can be classed along with the older gravels, and the only record of the early history of the Vaal is found in the sand-covered gravels of Droogeveldt, adjoining the Pniel Mission land and the Kimberley divisional boundary. The locality is known as Doorn Laagte. These gravels are from four to five miles from the river and at an altitude of 300 feet, if not more, and are spread over a gently undulating surface of diabase.

Though carrying diamonds of good quality the deposits have hitherto not been worked, owing to the lack of water in the vicinity.

Still further down the Vaal, thin washes of gravels are found east of Schmidt's Drift on the farms Vogelstruis Pan and Dispute up to an altitude of about 350 feet above the Vaal.

Of the terraces between Waldeck's and Delport's the highest which we find is a little patch on the top of a kopje about one mile north-west of Longlands, 80 feet above the river; while at Sydney, on the south bank, similarly situated gravels are being worked.

The gravels at Barkly, Waldeck's Plant, Gong-Gong, Niekerk's Rush, Longlands, Winter's Rush and Delport's Hope, form a terrace on a somewhat lower level (from 30 to 45 feet above the river-bed), while similar deposits occur at intervals further down the Vaal and at varying heights, *e.g.*, Schmidt's Drift, R.25, R.23, Atherton, and on the Douglas Commonage at the location.

At Wedburg (Windsorton) and Smith's Gully (Waldeck's Plant) there are channels only recently abandoned by the river, now filled with boulders and gravel. These deposits form what are known as deep placers as the thickness of gravel is frequently considerable. The floors of these channels are sometimes smooth, sometimes full of hollows and pot-holes.

Composition of the gravels.—The pebbles composing the gravels vary considerably in size, and it may be taken as a general rule that they are smaller and of more resistant material in the higher and older terraces. They are well worn and rolled, and commonly show percussion markings and cracks. The

agates being of a rather brittle nature frequently occur in rather angular pieces; the breaking up may be due in great part to sub-aerial weathering.

The pebbles consist of agate, chalcedony, quartz, variously coloured and striped quartzites, blue, black, yellow and brown banded cherts, jaspers and ferruginous cherts—locally known as "bantams"—lydianite and silicified wood.

The small rusty-weathering pebbles which form a very great proportion of the gravels are of extremely fine-grained quartzite.

Much of the material has travelled a considerable distance, as the banded cherts, quartzites and jaspers do not occur in the neighbourhood. Some have very probably been derived from the conglomerates of Taungs and Pokwani, but most of the material must come from the Transvaal. The agates, chalcedony and quartz are derived from the amygdaloidal lavas of the Vaal River Valley, and the silicified wood from the Karroo beds—of the Orange River Colony principally—the latter being usually in flattish pieces.

The lower gravels are crowded with boulders derived from the Dwyka conglomerate, and hence the abundance of diabase, amygdaloid, quartzite, porphyry, chert, etc. The greater number of these inclusions have not travelled very far, and were already rounded before they became incorporated in the gravels. In the deep placers such as the Wedburg (Windsorton), Smith's Gully (Waldeck's Plant), etc., the gravels consist chiefly of boulders from the Dwyka embedded in a mass of sand and pebbles. Some of these boulders attain a length of four feet and occasionally they still show striated surfaces.

Age of the terraces.—There can be no doubt that the highest gravels date back to a period when the topography was far different to that of the present day. When the oldest gravels were in process of formation the present valley of the Harts River had apparently not yet come into existence; since that period a broad valley has been excavated to a depth of over 500 feet.

In the earlier terraces I have not found any traces of palaeolithic man, but in those which are situated at altitudes of from 20 to 40 feet above the present river-beds water-worn worked implements are not uncommon.

Such occurrences have been recorded by Messrs. Johnson and Young* at Barkly West, Droogeveldt, Schmidt's Drift and Douglas, and there can be no doubt that man existed in this part of South Africa at a time when the rivers had not cut down to their present levels.

Near Barkly West, at a point nearly midway between the town and the bridge, rolled implements of diabase form no small proportion of the constituents of the gravels.

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* J. P. Johnson. Trans. Geol. Soc. S. A., Vol. IX., p. 53, 1906.

The age of these terraces cannot be fixed palaeontologically. The remains of *Mastodon*† in a 60 to 80 foot terrace at Waldeck's Plant, indicate that these lower gravels are either contemporaneous with or later than the fossil they contain.

Source of the diamond.—The discovery of diamond pipes shortly after the establishment of the diggings at once suggested a source for the gems in the gravels, especially as they are associated with small garnets and fragments of diopside and ilmenite.

This view was strengthened by the subsequent finding of blue-ground pipes in Barkly West close to and sometimes surrounded by diamond-bearing gravels.

The great objection to this simple solution was the important fact that the river stones were found as a whole to be superior in quality to the mine stones, and to this day they realise a higher price. Moreover, the stones from each of these two sources have characters which enable experts to distinguish them from one another; I am informed nevertheless that although it is comparatively easy to pick out a few mine stones from among a number of river stones, the converse cannot always be accomplished with the same degree of certainty.

Among the river stones are diamonds of all shapes and colours, and the proportion of yellow, clouded, spotted and fancy stones seems to be almost as high as among those from the mines; nevertheless, the former are superior in brilliancy and fire. There are several mines which produce or have produced diamonds approaching very closely indeed in their quality to those from the diggings. These mines are Jagersfontein, Frank Smith, Leicester, Balmoral, and Newlands.

We have seen that owing to the continual attrition during the formation of the gravels only the hardest materials have survived, and the diamond has not escaped, in spite of its extreme hardness. Mr. Ed. Williams, an expert diamond buyer, estimates the proportion of diamonds with their edges and angles worn at from 25 to 30 per cent.; for this information I am indebted to Mr. Rees, the Inspector of Claims at Barkly West. It is not necessary to suppose from this fact that the stones have been brought from a great distance, for the following reasons:—

The wearing of the edges of diamonds is not indicative of intense attrition, for it is well known that in boring with a diamond drill the stones may be considerably worn if the pressure applied to the crown is not great enough. Secondly, wherever the slope of the terraces can be determined we find evidence of gentle gradients in the river; the stones and pebbles may not have suffered so much from transport down stream as from wear by grinding in hollows and pot-holes.

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† R. Beck. Geol. Mag. p. 49, 1906.

The diamonds will thus come in great part from the areas which were drained by the Vaal River in times past; some of the stones may have come a distance, while others may have been derived locally. The wearing of the stones would tend to remove crystalline irregularities, etc., but the superior quality cannot be accounted for in this way alone. The invariable superiority of alluvial diamonds all the world over to the mine stones suggests that possibly the former may have been improved by prolonged exposure. Failing this, we are forced to assume that there are mines as yet undiscovered from which these superior diamonds have been derived. The many new occurrences of blue-ground discovered each year will no doubt in the near future afford more reliable data upon which to base conclusions.

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CAPE OF GOOD HOPE.

DEPARTMENT OF AGRICULTURE.

TWELFTH ANNUAL REPORT OF THE GEOLOGICAL COMMISSION.

1907.

Presented to both Houses of Parliament by Command of His Excellency the Governor, 1908.

CAPE TOWN:
CAPE TIMES LIMITED, GOVERNMENT PRINTERS.
1908.

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Twelfth Annual Report of the Geological Commission, 1907.

CONTENTS.

Geological Commission of the Colony of the Cape of Good Hope, 1907.

Cape Town,
31st March, 1908.

The Honourable
The MINISTER FOR AGRICULTURE.

SIR,—I have the honour to forward the report of the proceedings of the Geological Commission for the year 1907.

Good solid progress has been made in the scientific mapping of an hitherto untouched part of South Africa, work which has been carried on at the cost of no small hardship and discomfort to the members of the Staff, who have displayed a zeal in the pursuit of knowledge in a country hitherto only known to the trek-boer and the policeman, which is beyond all praise.

In view of the financial position the work of the Commission has been carried on with due regard to economy.

I have the honour to be,

Sir,

Your obedient Servant,

JOHN X. MERRIMAN,
Chairman.

GEOLOGICAL SURVEY

OF THE

COLONY OF THE CAPE OF GOOD HOPE.

DIRECTOR'S REPORT FOR THE YEAR 1907.

During the past year the work of the survey has been carried on in the country north of the Orange River and also in the Divisions of Hope Town, Britstown, and Prieska, south of the River.

I was in the field for six months, completing the survey of parts of Kuruman and Vryburg, and making a journey through Gordonia. Gordonia is chiefly covered with sand, but it is of considerable importance to know the nature of the limited number of outcrops between the German border and the Langeberg–Korannaberg ranges. Much of the Gordonia district is a difficult country to travel in on account of the scarcity of water and the heavy sand; but it was my fortune to make the acquaintance of the Messrs. Lannam, of Mount Temple, Kuruman, who helped the survey very greatly. Mr. Thomas Lanham came with me for some seven weeks through the worst part of the country and gave me the use of several oxen during that period and at other times. Owing to this help I was able to travel further and to get together much more information than would have been possible otherwise. Mr. Lanham has a very good knowledge of the country, and he spared himself no trouble in taking me to spots where he knew of outcrops. The season was a favourable one for travelling, and in spite of the large areas left untraversed the geological structure of the Gordonia Division, except the south-western corner which was left for a future journey, has been to a large extent made out. The chief results are the finding of a great extension of the Karroo beds over Gordonia, the existence of a

wide area of sedimentary rocks, probably continuous with the uppermost group of pre-Karroo sandstones and shales of the central Namaqualand plateaux, and the intrusive relation of the granite of Upington, etc., to the Kheis series. The character of three groups of rocks in the district and their distance from hitherto surveyed parts of the Colony leave doubt as to their relationship, and they have been given new names in consequence, but they may soon be definitely correlated with other beds in Bechuanaland and Griqualand West.

From September to the end of the year I was absent on leave, and had the honour of representing the Cape Survey at the Centenary Meeting of the Geological Society of London, which was held during the last week of September.

Mr. du Toit worked for three months in the west of Mafeking and Vryburg, by arrangement with the Public Works Department, with a view to giving advice as to the position of sites for water boring. The Public Works Department paid the expenses of this survey. He mapped a large area, which, however, largely consists of sand. His discovery of volcanic rocks belonging to the Kraaipan formation is of great interest and will probably be the means of correlating that group with beds in Gordonia, Kenhardt, and Prieska. He also obtained much information about the superficial quartzites, limestones and sands, which, together with my observations further west, throw more light on some difficult questions concerning the remarkable surface deposits of the interior of South Africa. Mr. du Toit also spent three months between Griquatown, Prieska and De Aar. His work included the examination of the southern extremity of the Kaap Plateau, a feature now proved to be to a great extent of post-Karroo age, and the survey of several inliers of volcanic rocks within the Dwyka area of Hope Town and Prieska, which has made clear the relationship of the several volcanic rocks there to the better known occurrences from Kimberley northwards to Bechuanaland.

We owe to the kindness of the Chief Engineer of

the Public Works Department the loan of some instruments which have been of much use in the field during the past year.

Sheet 45 of the Geological map has been issued during the year, and sheet 46 was prepared and printed. Sheets 42 and 52 are in the printer's hands. Two more, 49 and 50 are now being prepared.

Mr. Henry Woods' memoir on the Pondoland Cretaceous Mollusça was issued early in the year. Dr. F. L. Kitchin's work on the Uitenhage Mollusca is finished and is now in the printer's hands. Dr. B. N. Peach, F.R.S., has undertaken to examine the Crustaceans from the Karroo formation.

The following papers written by the staff were published during the year.:—

The Glacial beds in the Griquatown Series, by A. W. Rogers in Report of the S.A.A.A.S. for 1906.

Pipe-Amygdaloids, by A. L. du Toit, Geol. Mag. 1907.

ARTHUR W. ROGERS.

GEOLOGICAL COMMISSION.

General Abstracts of Receipts and Disbursements for the Year ended 30th June, 1907.

Receipts	£	s.	d.
To Balance 1st July, 1906	195	16	3
„ Government Grant	2,000	0	0
„ Refund of overpayment to Agricultural Department	0	10	0
„ Advances (Current), repaid by vouchers	290	0	0
„ Balances as per Cash Book	4	17	6
	£2,491	3	0

Disbursements	£	s.	d.	£	s.	d.
By Salaries	1,000	0	0			
„ Allowances, Personal	304	17	0			
„ do. Horse	17	5	0			
„ Transport	122	19	2			
„ Postages	22	5	8			
„ Printing, Books and Magazines ...	17	15	8			
„ Analysis	5	12	0			
„ Rock Sections	8	13	4			
„ Horse Purchase Loss	8	7	0			
„ Boys' Wages	48	18	0			
„ do. Food	40	6	7			
„ Purchase of Oxen and Donkeys ...	183	0	0			
„ do. Wagon	88	2	0			
„ do. Scientific Instruments ...	6	10	0			
„ Printing of large Scale Maps ...	151	2	0			
„ Equipment and Maintenance ...	56	8	8			
„ Description of Specimens	113	1	0			
„ Miscellaneous	5	18	8			
				2,201	3	0
„ Advances made				290	0	0
				£2,491	3	0

I certify that the above Account has been examined under my directions and is correct, and that the balance agrees with that shown in the Bank Pass Book.

(Signed) W. A. R.

(Signed) WALTER E. GURNEY,
Controller and Auditor-General.

Audit Office, Cape Town, 18th September, 1907.

THEODORE MACKENZIE, Secretary.

GEOLOGICAL SURVEY OF PARTS OF VRYBURG, KURUMAN, HAY, AND GORDONIA.

BY A. W. ROGERS.

GEOLOGICAL SURVEY

OF PARTS OF

VRYBURG, KURUMAN, HAY, AND GORDONIA.

BY A. W. ROGERS.

INTRODUCTION.

The country described in the following pages extends from near Vryburg through the Motiton, Genesa, and Morokwen Reserves to the Molopo at Kuis, and thence southwards to the Orange River and westwards to the German border. It includes the northern part of the Kaap Plateau and the Kuruman range, the Korannabergen, some of the mountains in Gordonia, the valley of the Orange River between Kheis and Upington and that of the Molopo (often known in that part as the Hygap) between the confluence of the Nossob and Ghous. The Molopo between Kuis and the Nossob was not visited. and a very large area, said to be entirely covered with red sand, lying between the Inkruip and Malanie hills on the east and the Hygap on the west, was not traversed.

The district is characterised chiefly by its general covering of sand and the scarcity of water, and it is the southernmost part of the somewhat ill-defined area called the Kalahari. In local usage the term Kalahari is applied to the country between the Langeberg-Korannaberg ranges on the east and the Nossob-Hygap valley on the west, but the eastern limit north of Korannaberg would seem to be difficult to define; there is no appreciable change in the nature of the country till the Heuning Vley hills are reached, and the area between the Korannaberg and the Kuruman range is of the same character as that north of it. The change from sand-veld to hard ground in that region takes place near Gamagara.[1]

Towards the south the sand-veld extends to the Orange River in many places, but between the tongues of sand which reach the river there are stretches of hard ground, extending in places six or eight miles from the river. On the west, near the Ger-

[1] According to the usage adopted by Dr. Passarge in "Die Kalahari." the name is applied to the predominantly sandy country south of the Congo—Zambesi watershed.

man border, the sand-veld becomes broken up by wide tracts of hard ground.

In the eastern and central parts of the district the rocks only crop out in the hills and a few valleys, but in the extreme west and south they are often visible over wide stretches of flat ground.

This district is one of little topographical relief; the surface slopes generally towards the south-west and south, where the Orange River runs at a level of about 2,300 feet above the sea. The highest points are on the Langeberg (6,011), Korannaberg (about 5,800), and the mountains of Gordonia, but the highest part of the district is the north-eastern corner, the northern portion of the Kaap Plateau. The surface slopes very gradually towards the Hygap and Orange Rivers.

The hill ranges are the Kuruman-Heuning Vley ranges (the direct continuation of the Asbestos hills of Griqualand West), the Langeberg-Korannaberg range, the mountains of Gordonia called Scheurberg, Inkruip, Kamkuip, Karreeboomberg, and a few other smaller hills, and the small irregularly-shaped and usually dolerite-capped hills near the German border.

The rivers all join the Molopo and Orange River. Their courses are often very slightly defined; at places they may be crossed without being noticed by the traveller. The Molopo near Kuis, however, has a cañon-like valley over 100 feet deep, and the same is the case with the Hygap for some 15 miles near Zwart Modder. There is seldom running water in these river beds; during my journey there were pools in the Kuruman River at Gasese, in the Mashowing at Madebing, and a large pool in the Molopo at Zwart Modder.

From inquiries made it appears that water has not run continuously from Kuis on the Molopo down to the Orange River within the memory of living man. That part of the Hygap below the farm Bloemfontein carries water to the Orange River after heavy local rain, but it receives no supply from above Abiam. When the Kuruman River, Nossob, or the Molopo "come down" the water does not pass Abiquas Puts; it is there turned out of the old course by drift sand and diverted westwards to the flat ground on Abiquas Puts. The exceptionally heavy rains of 1894 made the Kuruman River flow, and it was from this source that a large area on Abiquas Puts was flooded. The accumulations of drift wood then carried down by the Kuruman River are still to be seen below Lower Dikgathlon. On that occasion the Molopo and Nossob apparently did not add any water to that which flowed down the Kuruman River.

There are no laagtes (dry valleys) entering the Kuruman River below the confluence of the Mashowing, nor are there any joining the Molopo along that part of the valley near Kuis examined by me. The short kloofs on the Molopo between Kolingkwane and Kuis soon attain the general level of the country between the Molopo and the Kuruman River,

The Kuruman River is joined by the Mashowing at Lower Dikgathlon,[1] and the Mashowing is joined by the Kgogole Laagte at Madebing. North of the Kgogole all the laagtes lead directly to the Molopo; the chief of these are the Matamatobo, which the Pepani laagte joins south of Morokwen, and the Genesa laagte, which receives some smaller ones, the Mofanie, Thlakgaming, and others.

The geological structure of the area is simple in the west and north-west, but it becomes complicated in the central part, which is unfortunately the area where the rocks are most completely hidden under sand. Along the extreme southern edge, however, the rocks are exposed; and from the structure of that strip of country and the mountains in the Kalahari it is obvious that the more ancient sedimentary beds have been greatly disturbed, and that igneous rocks have played an important part in the making of Gordonia. It is not only the superficial deposits of more or less recent date, such as the Kalahari sand, that cover the more ancient rocks, but there certainly is a very extensive, though comparatively thin, layer of beds belonging to the Karroo formation in this area. These Karroo rocks are first met with about 15 miles north of Upington, and are widely exposed between the Hygap, which has cut through them below the confluence of the Molopo and Nossob, and the German border (long. 20° E.). That they underlie some of the sand-veld between the Hygap and the Korannaberg is proved by the fact that in the four wells in that region from which rocks other than superficial deposits have been obtained, viz., those at Norokei, Eenzamheid, Witdraai, and Matlapanin, the Dwyka series is met with. The specimens from the two first-named localities were obtained by Dr. Eric Nobbs during a journey made by him on behalf of the Agricultural Department in 1903,[2] and they were brought by him to the office of the Geological Commission; they were the first known evidence of a large outlier of Karroo rocks north of the Orange River and west of Griqualand West. Owing to the determination of these specimens and the special circumstances of my last journey, I left those two wells unvisited, but the southern edge of the area covered by the Karroo formation was found, and the country west of the wells was traversed. The Witdraai and Matlapanin wells gave the only information on the "solid" geology got between the Hygap and a line drawn between Kuis and the Kuie rocks. The Karroo rocks are seen to fill ancient north-south valleys in the Matsap beds between Kuis and Kolingkwani, and they extend into the Bechuanaland Pro-

[1] Both the Mashowing and Kgogole laagtes are wrongly marked as leading north-westwards to the Molopo in all atlases looked into, even in Stieler's Hand-Atlas, 1907 edition. Their true courses are indicated on the Divisional Map published by the Surveyor-General.

[2] E. A. Nobbs, Parl. Reports, C.G.H., G. 39, 1904, Cape Town.

tectorate. They also stretch westwards across the German border. This evidence from so large an area, though obtained at so few places, undoubtedly indicates the presence of a very large outlying mass of the Karroo formation, and we are still ignorant of its western, northern, and eastern limits; it may well cover 10,000 square miles in Gordonia. These Karroo rocks lie flat upon an undulating and in places deeply eroded surface of older rock; they were not met with below an altitude of about 2,700 feet above sea level.

The oldest sedimentary beds seen belong to the Kheis group; they are chiefly mica schists and quartz schists, and they have been invaded by granite. These Kheis beds are separated by a great stretch of newer rocks from undoubted Kraaipan beds, which are the oldest sedimentary rocks known in the north-eastern part of the area; according to Mr. Du Toit's work, the Kraaipan beds have not been shown to be older than the Bechuanaland granite, and my recent observations do not invalidate that statement. There is no direct connection, traceable at the surface, between the Bechuanaland and Gordonia granites. Though correlation with the Kraaipan beds cannot be proved at present, there are beds along the Orange River below Kheis which may belong to the Kraaipan series. These beds are of sedimentary and volcanic origin, and are described below under the name of the Wilgenhout's Drift series. Like the Kraaipan formation, this group has not been found to be invaded by granite.

The Vaal River (Ventersdorp) System is represented by a few detached masses of rock in the north-eastern part of the area, and possibly by some rocks, described below under the name of Koras Series, which occur along the Orange River above Upington.

Rocks belonging to the Transvaal System form a great westerly dipping mass in the north-east of the district. The lowest group of these rocks, the Black Reef Series, makes an escarpment from Motiton down the south side of the Mashowing valley to Garaphoane, where it turns northwards and trends N.N.E. through the Morokwen Reserve; the Campbell Rand group follows to the west, and the area occupied by it is the north end of the Kaap Plateau. The Lower Griqua Town beds form the Kuruman-Heuning Vley-Skelek range, the continuation of the Asbestos Mountains of Griqualand West; they are followed westwards by the Middle Griqua Town beds, which are rarely exposed. There is uncertainty as to the manner in which the Transvaal formation comes to an end on the eastern side of the southern Kalahari; the angle of dip becomes higher towards the Langeberg-Korannaberg range, and within the Korannaberg highly-inclined beds belonging to the Transvaal System are exposed along the axes of overturned anticlines of the Matsap Series, but west of that range there have been found only Kheis, Matsap, Dwyka, and other rocks which cannot yet

be identified with any member of the Transvaal System; whether one of these other groups may partly represent that system will be discussed later.

The Matsap beds form the Langeberg-Korannaberg range, which makes a wide curve round the south-eastern Kalahari, and some of the mountains within it; they cross the Molopo into the Protectorate between Kuis and Kolingkwane, but they have not been recognised west of the Karreeboom Laagte hills.

The extreme western part of the district north of Ghous is characterised by the presence of almost horizontally-lying sandstones, quartzites, and shales, which rest unconformably upon granite and schists, and are unconformably overlain by the Dwyka Series. This group of arenaceous rocks, here called the Zwart Modder Series, has not yet been correlated with any other group in the Colony, but it is certainly a very important element in the geology not only of Gordonia, but of the eastern part of German South-west Africa. It extends from Ghous on the Hygap past Rietfontein and westwards across the German border. Excepting the anticlinal fold near Sannah's Poort, no considerable disturbances have been noted in these beds.

The recent and sub-recent deposits are of great importance in this district. They include sand and various rocks formed by cementation of sand by calcium carbonate and silica, and rocks chiefly composed of calcium carbonate or of silica.

THE KHEIS SERIES.

In the Annual Report for 1899[1] some quartz schists and associated rocks were described from the Prieska division under the name of Kheis beds, because they appeared to be continuous with the rocks in the Kheis area north of the Orange River, marked on Stow's map.[2] This year's work has shown that the schists at Kheis are just like those of Brakbosch Poort hills in Prieska, and there can be no doubt that the rocks in the two areas belong to one series and are in continuity beneath the Orange River. A previous year's work[3] showed that the supposition of Stow that the schists of Kheis are represented by some rocks in the Campbell Rand escarpment at Leijfontein was an error. The Kheis beds have not yet been identified west of Hay, Kuruman, Gordonia, and Prieska.

The rocks included in this series are chiefly quartz-schists and quartzites; by the increase of the proportion of mica they become mica-schists. There are also some gritty rocks and magnetite and other schists.

[1] Ann. Rep. Geol. Comm. for 1899, pp. 73—76.
[2] Quart. Journ. Geol. Soc., vol. XXIX., 1873, pl. XXXV.
[3] Ann. Rep. Geol. Comm., for 1905, p. 153, and Trans. Geol. Soc., S.A., vol. IX., p. 1 and pl. II. Stow., *loc. cit.*, p. 660.

The series crops out along the Orange River below Buchu Berg, and appears at the surface for some 34 miles down the river as far as the farms Sterkstroom and Groot Drink. It reappears on Koras, and stretcnes thence to Upington Common. It probably underlies a great area north of the river near Kheis, but in that country the rocks are only seen at Scheurberg, England, the Gamotep, and Kuie ridges, and in a few other small hills; north of Sand Kuie they are almost entirely hidden under the sand within the Colony, so the northern limit of the Kheis beds is unknown.

The nature of the junction with the Matsap beds of Buchu Berg, which is geologically a part of the Langebergen, has not yet been determined.

The quartz-schists make low outcrops on Zaal Werf and Tsebe, and on Tsebe there is a brownish-grey gritty rock interbedded with them. This gritty rock is well bedded, and there are several bands of it, the thickest being 30 feet and 100 feet thick respectively; these two occur on the sides of thick dykes of dolerite of the Karroo type, but the thinner bands, some of which are lenticular and thin out when followed along the strike, are quite independent of the dykes. In hand specimens the grits have a strong resemblance to rocks belonging to the Malmesbury series in the Cape and other South-western Divisions. A thin section (1761) cut from one of the large bands of rock is seen under the miscroscope to be made up chiefly of grains of quartz and a turbid substance, which have a distinct parallel arrangement. The quartz areas are clear, but contain a few dusty inclusions and very small flakes of mica; they interlock completely after the manner of the quartz in quartz-schist, and the boundaries of originally detrital grains are not visible, though from the appearance of the rock to the unaided eye one would expect to see such grains under the microscope. The cloudy material is a biaxial mineral, and has the appearance of felspar considerably decomposed; it contains very minute flakes of sericite and much brownish dusty matter. There are also epidote and small crystals of magnetite, evidently developed in place. The only other determinable minerals are sericite and calcite, which are present in small quantity only.

Thin layers of magnetite-schist, which is merely quartz-schist very rich in magnetite, occur on Kheis, but neither here nor elsewhere in Gordonia do such magnetic rocks form a considerable part of the Kheis series, as they do of the Kraaipan group of Bechuanaland and of certain masses of rock within the Prieska granite area formerly supposed to be detached portions of the Griqua Town series.

Some green schists associated with the Kheis beds along the Orange River are found on microscopic examination to be so like rocks that were taken from what were evidently intrusive dykes that tney will be described with these on a later page.

The strike and dip of the Kheis beds below Buchu Berg vary

greatly, and it was impossible to trace out the stratigraphical succession of different bands of more or less micaceous rock. On Zaal Werf, Tsebe, Brand Boom, and Kheis the strike changes from E. 20° S. to N. 10° E., but does not appear to turn west of north; below Kheis a north-westerly direction predominates between Spitzkop and Sand Draai, and towards Sterkstroom the strike turns more and more towards E.N.E., parallel to the limit of the series on Sterkstroom and Groot Drink. This boundary line is a fault, for on the north-western side not only are the rocks and their structure quite different, but such that there cannot be an unconformity along the line. Near the river a large mass of intrusive diabase (see p. 86) separates the Kheis rocks from the group described below under the name of Wilgenhout's Drift Series, but about 2½ miles from the river bank one passes abruptly from the Kheis beds with E.N.E. strike on to well-bedded quartzites with bands of mica-schist, which have a steady dip towards E.N.E., and form a series of parallel hill ranges with the same strike as far out as the Karreeboom Laagte hills. The uniform strike of these rocks and their distinct bedding throughout the parts seen separate them sharply from the Kheis beds, though portions of each in hand specimens have considerable lithological similarity; they cannot be traced continuously into rocks whose age is known, for they are isolated on the north and east by the Kalahari sand. I was in doubt as to their relationship when amongst them, and further work in the district did not wholly remove the difficulty, but owing to their parallelism of strike with the Matsap beds of the ranges further east and a considerable lithological resemblance to the Lower Matsap group of the eastern foothills of the Langebergen (including the presence of a band of conglomerate at the base), they will be placed in the Matsap series in this report.

On Rooi Sand some hills trending N. 40° E. rise from the area of Kheis beds at a distance of 2½ miles from the river, and are continued as the Tities Poort range. They consist of quartzites and quartz-schists, which certainly belong to the Kheis series. The north-eastern part of the range has not yet been examined, but especial interest is attached to it because it must somewhere meet the western group of mountains on the farm Scheurberg, which at least at their northern end are made entirely of Matsap beds. Whilst the Tities Poort range on Rooi Sand trends about north-east, the western range on Scheurberg has a north-north-westerly course.

There are at least five small hills formed by the Kheis quartzites and schists on Tities Poort and O Poort; the strike of the southernmost of these rocks is N.N.E., but on O Poort they turn to a few degrees west of north.

The Kheis beds in this area are traversed by numerous dykes of amphibolites and dolerites (see pp. 82-85), by three masses of granite (see p. 22) and by two kinds of quartz veins. The

older quartz veins are of pinkish and white granular or sugary quartz, and they do not appear to contain sulphides; the later veins are of ordinary quartz, containing both iron and copper sulphides, which at places have given rise to red and green stained outcrops.

The mountain called Scheurberg on the farm of the same name is made entirely of the Kheis beds. It is by far the most rugged range in Cape Colony north of the Orange River, though it is not so high as many parts of the mountains formed by the Matsap and Griqua Town series. The length of the range is only six miles; the highest point, where a beacon of the Geodetic Survey stands, is 4,317 feet above sea level,[1] but only 880 feet (by anaeroid) above the flat sandy ground near England, five miles to the north-east. The rugged surface is due to the action of the weather on the alternating harder and softer bands of quartzite, quartz-schist, and mica-schist which make the mountain. The Matsap and Griqua Town series are more uniformly resistant to the weather, and therefore give rise to less jagged ridges.

By far the greater part of Scheurberg is made of quartz-schist; pure quartzites are seldom seen; rocks which look like quartzites on the outcrop present a freshly broken surface covered with very minute flakes of mica. Those rocks which contain rather more mica break up under the influence of the weather into long, but thin slabs. Magnetite occurs in thin bands on the eastern side of the mountains, and these bands, which presumably coincide with the bedding planes, are often highly contorted. The strike throughout the mountain is N. 20° W., and the dip may be in either direction. The planes of schistosity have the same strike as the beds, but their dip is more regular, though they have a sharply anticlinal arrangement, for they dip in an easterly direction on the east side of the mountain and westwards in the central and western parts.

The quartz veins seen were all of the sugary type mentioned in connection with the Kheis beds. They are frequently broken and separated into more or less lenticular streaks parallel to the schistose planes of the enclosing rock.

About five miles north-east of Scheurberg beacon there are two low outcrops of the Kheis beds at the place called England. The largest outcrop is only 100 yards long, and rises to a height of 8 feet above the sand. The rock is a fine-grained quartz-schist like the harder part of the schists of Scheurberg. The strike of the schists is N. 10° W., and there are three sets of well-developed joints, S. 35° W., S. 45° W., and N. 40° W. The surface of the rocks is rather highly polished by sand blown across it by the wind, and there are several holes in it, the deepest of which is more than five feet deep. These holes are filled by the rain and hold water for a long time, unless it is used up

[1] Rep. of the Surveyor-General for 1901, p. 9.

by passing travellers. The place is well known, and is the only spot where water can usually be found on one of the chief routes between the river above Upington and the Langeberg.

Four small patches of quartz-schist with strikes of N. 15°—30° W. were seen between Scheurberg and Inkruip, but in this area generally the red sand completely covers the rocks.

The Kheis beds appear again in the long line of kopjes projecting from the sand at various intervals from near Gamotep to Klein Kuie, a distance of some 30 miles.

The southernmost of the Gamotep rocks is 300 yards long and 100 wide; it rises about 100 feet above the sand, and is visible from a considerable distance to the east. It is made of a very hard quartz rock, which has joints or divisional planes of some kind striking N. 10° W., and less numerous joints lying E. 10° S. The rock seems to be vein quartz, not a quartzite of sedimentary origin, and it is brecciated in places. A rough schistose structure with thin films of sericite makes the rock break into irregular lenticular masses in parts. The Gamotep rock proper is not visible from a distance, for red sand downs rise round it; it lies about a mile north-west of the prominent southernmost kop. It is a sand-polished surface of quartz-schist and mica-schist, about 450 yards long and 100 wide, with long and deep rock holes in it. The strike of the schists is N. 20° W., and the rock holes, of which the largest contained a sheet of fresh water about 50 yards long by 20 wide and 8 feet deep at the time of my visit, are elongated in that direction. The rock is just like that of Scheurberg. Small kopjes of the same rock project from the sand about a mile north-north-east of Gamotep, but the strike there is N. 10° W. Along the western side of the Gamotep Pan, which lies nearly 5 miles north-north-east from the water-hole rock, the quartz-schist is exposed, but it then disappears for several miles, to emerge again in Malanie Kop and along the western side of the two pans near it. The next outcrops are those of the Kuie Block, where the schists are exposed more or less continuously for a distance of 9 miles from south to north, and I was told that some small outcrops occur much further north along the same line (about N. 10° W.), between Sand Kuie and the Kuruman River, but the schists do not crop out in the Kuruman River, nor, according to information from various people, do they appear at the surface in the Molopo.

In the Kuie Block the rock is of quite the same type as at Scheurberg, chiefly quartz-schist, but quartzites and mica schists also occur. They are exposed over a great part of the floor of Kuie Pan, and make a long ridge, which rises to a height of more than 200 feet above the floor of the pan, on the west side of it, and smaller kopjes on the east and north-east. The strike of the rocks in the Kuie Block varies from N. 5° E. to N. 15° W., but the predominant direction is N. 10° W.

The rock forming the kopjes east of the pan is white or grey

in colour, and all parts of it show one or more glittering micaceous surfaces when broken. Under the microscope a thin section (1752) is seen to be made chiefly of quartz with many dusty intrusions scattered more or less uniformly through it, a little white mica, and some magnetite. The quartz individuals are of fairly uniform size, and neighbouring quartzes often fit closely together without the intervention of anything else, so that the distinction between them may be visible only when seen between crossed Nicols. The quartz does not show strain shadows. Many of the quartzes contain smaller ones differently orientated within them. The mica is colourless, and occurs chiefly between quartz areas, but very small flakes are enclosed by quartz. The magnetite often has crystalline form but it is usually collected in thin strings, layers seen in section, parallel to the schistose planes in the rock. There are a few small highly refracting and doubly refracting prismatic crystals of a pale yellowish brown colour, probably zircon.

The rock exposed on the floor of the pan is green, as is often the case with rocks in salt or brak pans. In a well at the edge of the pan the quartz-schist is seen to keep the green colour at least 30 feet below the surface. It has a bright green colour, and the schistose structure is well developed. A thin section of this rock (1751) is seen under the microscope to be made of quartz, mica, garnet, and a very little magnetite. The quartzes are of uniform size, and are generally like those in the rock just described, but the dusty inclusions are less frequent, though there are layers of a dusty material along the surfaces of contact between neighbouring quartzes and in narrow zones within the quartzes parallel to those surfaces, also along the cleavage cracks of the mica. Instead of having the brownish colour of the inclusions in the grey rock just described, they have a greenish yellow colour in transmitted light under the microscope and are evidently the colouring matter of the rock. The quartz shows no strain shadows. The mica is colourless itself, but owing to the greenish dust along the cleavage planes and between this mineral and the quartz, patches of the mineral larger than the smallest flakes have a green tint under a low power. The garnet is in small grains, in some cases with crystal faces; it is colourless, and quite isotropic.

The quartz veins in this neighbourhood are chiefly of the sugary type.

Below Sterkstroom on the Orange River there are no rocks that can be referred to the Kheis series for some 20 miles down the river, where the kopje on which the Brak Pan beacon stands is formed by quartzites of uncertain relationship. About 10 miles beyond this kopje, and separated from it by later rocks the typical quartz of the Kheis series reappear on the farm Koras. These schists are brought up against the Koras conglomerates along a fault which trends north-west, but for about a mile near the river there is a mass of intrusive diabase (sec

p. 86) along the fault; this diabase is of the same type as that forming intrusions at Groot Drink and Leeuw Draai. From Koras the schistose rocks extend continuously down the river past Uizip beacon to the farm Melkstroom, whence they stretch north-westwards through the north-eastern part of Upington Common. They also form a considerable range of hills between Steenkamps Pan and the Common. Though these rocks below Koras are chiefly quartz-schists, identical in character with those of Kheis and Scheurberg, they also include great thicknesses of other varieties of rock, which are either not so well developed in the east or have not yet been found there.

On Koras these rocks are highly disturbed but the dominant strike is about east and west; further from the Koras fault the strike lies between north-north-west and north-west, with high south-westerly dips. They include quartzites, quartz-schists, mica-schists, and phyllites of a dark colour and much finer texture than the usual mica-schist. On Uizip and Kameel Poort there are many bands rich in magnetite, but quartzites and greatly crumpled mica-schists make up the larger part of the rocks here. There are also thick bands of a brownish quartzitic looking rock on Kameel Poort with sub-conchoidal fracture; it has a peculiar mineral composition. Under the microscope (1796) it is seen to consist largely of quartz, which has a strongly schistose structure; the quartzes are all elongated in one direction and the larger individuals show strain shadows; the other constituents are monoclinic pyroxene, colourless amphibole, calcite, and magnetite. The pyroxene is colourless, and has the optical properties of colourless augite, but the prismatic cleavages are not well devloped; it occurs in rather large irregularly shaped masses, which enclose small round areas of quartz and also magnetite and flakes of amphibole; it is not arranged in any uniform way nor is it strained like the quartz, so it must have been developed subsequently to the schistosity of the rock. The amphibole is similarly independent of the schistose structure, forming small flakes, distributed irregularly through the rock; it is colourless and not fibrous, with extinction angles up to 18°. The amphibole, like the augite, is quite fresh. The calcite occurs in small patches throughout the thin slice examined.

There is no intrusive rock seen in the immediate neighbourbourhood of this quartzitic rock which would account for the development of new minerals. Some amygdaloidal lava of the Koras series is within a few hundred yards of this rock, but even if the lava outcrops mark the position of a vent, which may be the case, the pyroxene and amphibole in the schist are evidence of too great a change to be attributed to the proximity of the lava.

Near the fault on Koras there are large masses of a conglomeratic rock, with a matrix of mica-schist and lumps, some of them rounded at the edges, of quartzite, quartz-schist, and

vein quartz; this is almost certainly a crush-breccia and not a conglomerate of sedimentary origin; neither here nor in any part of the Kheis beds hitherto surveyed have undoubted sedimentary conglomerates been observed.

On Uap thin layers of hornblende-schist, often only half an inch thick, are interbedded with the quartz-schist and some of them were traced through 300 yards without change. In one case the hornblende-schist layer gradually thinned out, just as a sedimentary bed of different composition from the rest might do. These hornblende-schists were not found to cut across the quartz-schists.

The Kheis beds of this area are bounded on the south-west by the Upington granite as far north as the farm Christiana, where the Karroo formation covers both the older groups. Between the typical rocks of the Kheis series and the massive granite of Upington Common there is a belt of schistose rocks, the origin of some of which is doubtful, but as a whole they appear to be the contact zone of the great granite intrusion. There is no sharp line of demarcation between the massive granite and the bordering gneisses on the one hand, nor between the latter and the typical quartzites and quartz-schists on the other; bands of gneiss occur in amongst the quartz-schists within a mile of the boundary.

Just below the Government Offices at Upington there is a large mass of mica-schist surrounded by granite which sends many veins into the schist. The veins are exposed in the road cutting down to the drift and near a tunnel cut through the schist for the water-furrow. The schist is much contorted; the main surfaces of its contact with the granite lie nearly north and south, and are more or less vertical.

In the angle between the Hygap and the left bank of the tributary from Grond Neus there is a small inlier of granite and schist surrounded by quartzites of the Zwart Modder series (see p. 31 and fig. 1). The schists, which may be placed in the Kheis series, strike N. 25° W. They are mica-schists and garnet-sillimanite schists, which will be described below.

The Granite and Gneiss of Gordonia, and their Relation to the Kheis Series.

The first mass of granite met with on the right bank of the Orange River below Buchu Berg is on Spitzkop and Rooi Lye (see fig. 2). It is a wedge-shaped prolongation of a larger area in the Kenhardt Division. The rock is red in colour, owing to the red felspar in it and in many parts it has a strongly developed gneissose structure, the foliation planes lying parallel with the schistose planes in the Kheis beds near it; in other parts it is a hard compact rock with little mica, and shows no foliation.

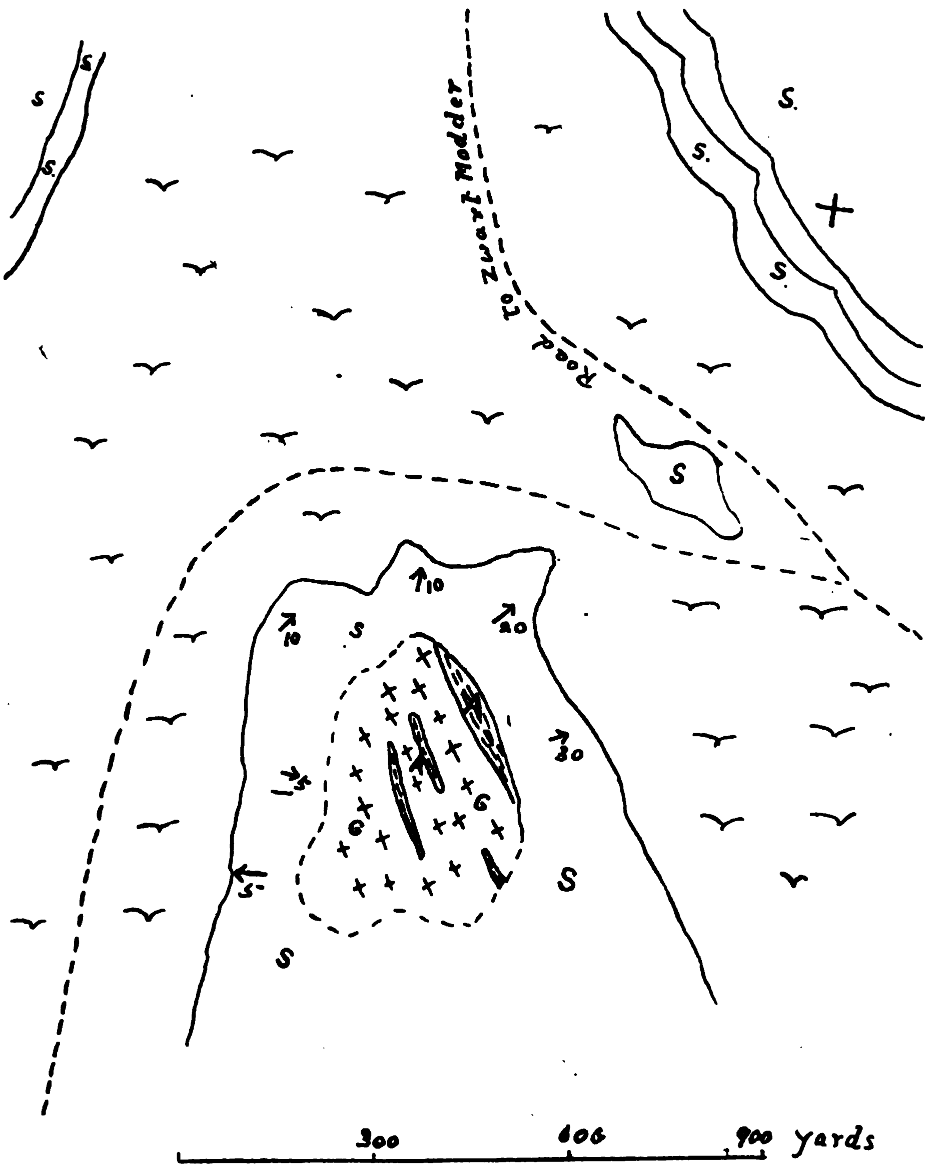

FIG. 1.—Plan of inlier of schists (A) and gneissose granite (G) in sandstones and quartzites of the Zwart Modder series (S). The alluvium and gravel mark the position of the beds of the Hygap and the valley from Grond Neus.

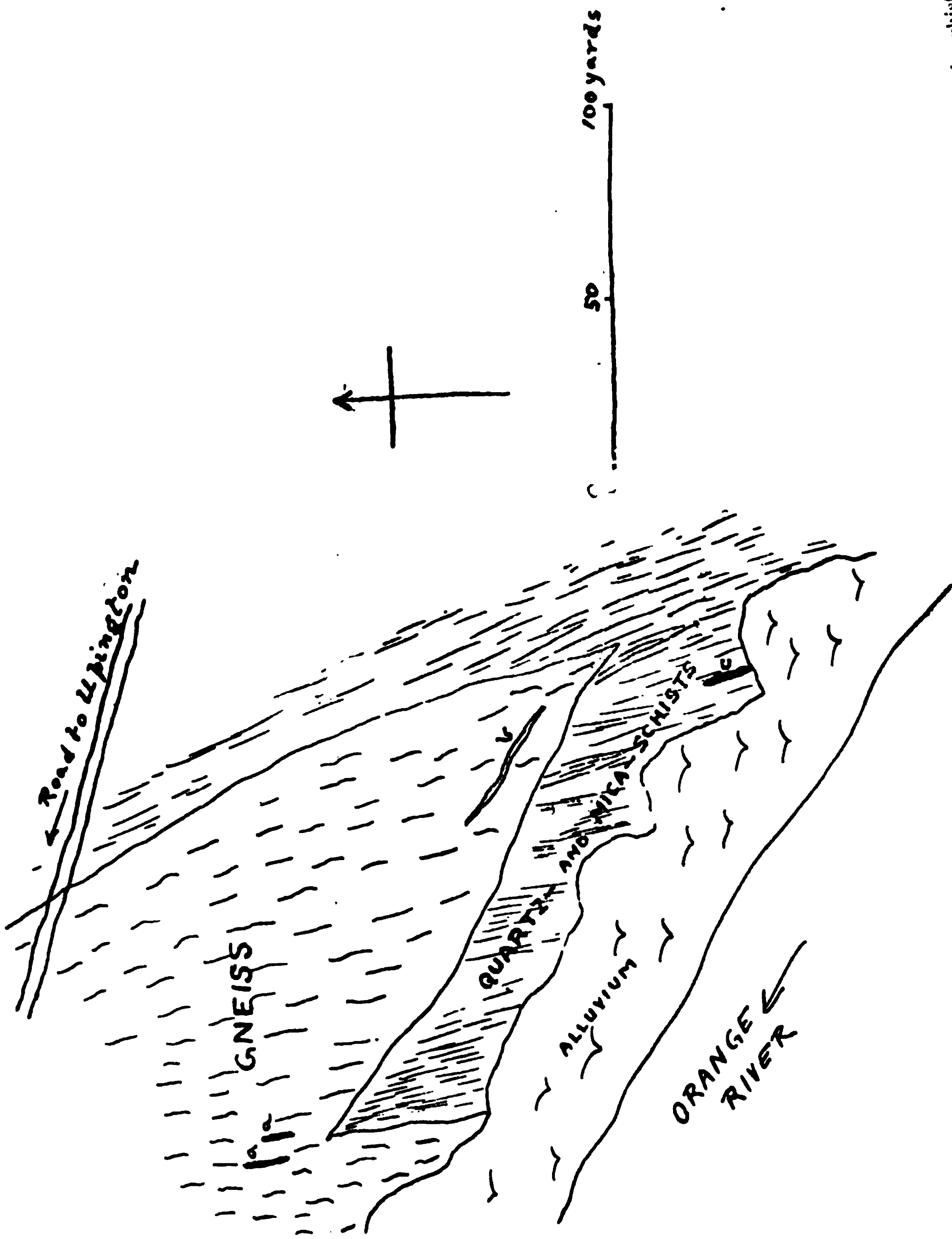

FIG. 2.—Plan of gneiss and Kheis beds on Spitz Kop. *a*, Quartzitic bands in the gneiss; *b*, quartz-felspar vein; *c*, hornblende-schist.

It is rather deeply weathered into a gritty mass, but the felspars are not much decomposed. Three thin sections (1771-3) from this gneissose granite have been examined; all of them show the effects of crushing. A red gneiss from Spitzkop (1771) is made of quartz, felspar, white mica, chlorite and some epidote. Most of the felspar is microcline, often in rather large patches of irregular shape, more or less completely surrounded by a zone of quartz or quartz-felspar mosaic; a similar mosaic occurs in bands traversing the slice. Some of the felspar is probably orthoclase and is crowded with small flakes of sericite. Both the quartz and felspar are crossed by many lines of minute inclusions or holes lying nearly perpendicular to the foliation; the larger individuals of both quartz and felspar show strain shadows. Another gneissose rock from Spitzkop (1772) is made of microline, quartz, and an acid plagioclase, and muscovite; it has been broken up, and the fragments of quartz and felspar are set in a matrix of quartz and felspar mosaic with sericite, the latter mineral also fills small cracks in the fragments and wraps round them. A massive-looking rock from Rooi Lye (1773) is seen in thin section to have been crushed; the large fragments are of quartz microcline and acid plagioclase, which are enclosed in a matrix largely made of quartz and albite.

This gneissose granite is traversed by veins of white opaque quartz containing pink orthoclase felspar in small patches; the veins usally lie parallel to the foliation of the gneiss, but they cut across the foliation in places; one of them is 50 yards long and 2 feet thick. They are like the quartz and felspar veins which occur in some dolomites at Zeekoe Baard in Prieska.[1] They are certainly of the same nature as the usual quartz veins found in rocks of various kinds, and are not of igneous origin in the sense that a dyke of granite is.

The contact of the gneiss and the Kheis beds is well exposed near the river on Spitzkop. Some specimens were taken from what were considered to be Kheis beds at various distances from the junction, and thin sections from them are described below. The contrast between the red gneissose granite and the grey schists is very marked in the field, but excepting the absence of microcline from the schists the two groups of rocks are in many ways very much alike as seen under the microscope. A slightly micaceous quartzite (1763), a grey rock striped with rather darker bands, and having a conchoidal fracture, taken from about 200 yards from the granite, is made chiefly of quartz in areas of more or less uniform size, without quartz mosaic between them; no strain shadows were noticed. Muscovite occurs in small flakes between quartzes or enclosed in the quartz grains; the flakes are often placed parallel to each other, but not in all cases. Magnetite is present in small quantity. No

[1] Ann. Rep. Geol. Comm. for 1899, p. 78.

felspar was seen. Cracks in the rock are filled with quartz mosaic. There are a few small grains of zircon (?) without crystal faces.

A similar looking rock (1764) 40 yards from the gneiss has a fair amount of epidote and some striped felspar. The quartzes are elongated in one direction, and most of the muscovite flakes lie in the same direction with which the strings of epidote grains are also parallel. There is a little magnetite and chlorite. The quartzes show slight strain effects.

A rock (1765) with the same constituents as the last, with the addition of calcite along broken bands, was taken at 30 yards from the granite. The schistose structure is well developed.

A rock (1766) 12 yards from the contact has the same constituents as those from 30 and 40 yards, but the epidote is in much larger quantity and there is more chlorite; there are also some ill-developed crystals of apatite and grains and crystals of zircon and sphene. The parallel arrangement of all the constituents is very strongly marked, and the quartz and felspar are traversed by lines of very minute, dusty inclusions and holes arranged perpendicularly to the planes of schistosity; the epidote is frequently cracked in the same direction.

A specimen (1767) taken from within a foot of the gneiss is made of the same constituents. The quartz and felspar areas are less equal in size, and there are streaks of quartz-felspar mosaic parallel to each other, but perpendicular to the lines of minute inclusions; it is only in the parallel bands of mosaic that the schistose structure of the rock is seen. A second specimen (1768) of rock taken from the contact at another spot has a very similar character, but it contains some apatite.

Two short bands of grey quartzitic rock were noticed lying in the red gneiss within 10 yards or so of the contact; they are only three or four inches thick and a few feet (under 15) long. Under the microscope (1769, 1770) they are seen to consist of much quartz and less felspar, which is chiefly an acid plagioclase, though some microcline is also present, a fair amount of chlorite, a little muscovite in very small flakes, and patches of a much cracked and partly decomposed, highly refracting isotropic, colourless mineral, probably garnet. The quartz and felspar are in areas of fairly uniform size, and are only slightly elongated parallel to the schistosity; the chlorite is chiefly arranged in the same direction. The lines of brownish dusty inclusions are perpendicular to the schistosity, and the larger specks are seen under an eighth-inch objective to be holes probably filled with liquid. This rock differs from the other schists in the presence of a small amount of microcline.

The most quartzitic members of this group of schists are without doubt very similar to, or identical in character with, a great thickness of rock belonging to the Kheis series, and the increasing amount of felspar and epidote is probably to be attributed to the influence of the granite. If the latter were not an intrusion

but an older rock upon which the Kheis beds were laid down, one would expect to find the felspars in the schists considerably altered, whereas they are fresh, as though they are newly-developed minerals. If they were debris from a pre-existing granite, they would probably be chiefly microcline and orthoclase, but they are chiefly, at least, an acid plagioclase. The rocks found as inclusions in the gneiss, though taken in the field to be fragments of quartzite, may have had a different origin, though it is possible that the microcline substance in them came from the gneiss, and that they are really sedimentary rocks, with more additions from the granite than were given to the enclosing schists.

The rocks have certainly been considerably disturbed since the intrusion of the granite, for the latter, in addition to the gneissose structure, has been broken up, and the parts re-cemented by quartz-felspar mosaic. This fracturing process has had the effect of obliterating the foliation of the rock to some extent, and was probably brought about long after the foliation, which, as it is parallel to the schistosity of the enclosing rock, may have been produced during the intrusion or before the rock finally cooled.

On Leeuw Kop there is another wedge-shaped prolongation of granite on the right bank of the river; it is a red gneissose rock like that of Rooi Lye and Spitzkop, and the foliation is parallel to the schistose planes in the immediately surrounding Kheis beds, striking about N. 15° E. The schists here are of the same character as those on Spitz Kop, but they have not been studied under the microscope.

On Zwem Kuil there is a thin band of highly micaceous gneissose granite in the schists, which here contain very much mica, and are in consequence more deeply disintegrated than usual.

Between the Melkstroom-Steenkamp's Poort hills and the granite of Upington there is a band of schistose rocks, quite a mile wide across the strike, which differ in some respects from the ordinary quartz-schists of the Kheis series. Some of these rocks have been examined under the microscope.

A rock on Uitkomst (1801), taken for a quartzite in the field, consists chiefly of quartz with strongly marked schistose arrangement; large neighbouring quartzes are often separated by quartz mosaic, and the large quartzes always show strain shadows; there is a small amount of felspar, some of which is plagioclase and some untwinned; it is rather cloudy, and some of it contains many small flakes of sericite. There is also a small amount of white mica and greenish weathered biotite, and a very little magnetite, sphene, and zircon in minute crystals. Three other slices (1802-4) from rocks on the same farm are

similar to the above in general character, but have somewhat more felspar, and part of the felspar is microcline; they also contain epidote and chlorite, the former of which appears to have developed from felspar. In one slice (1804) the muscovite is in much larger flakes than usual, but does not show the strain effects exhibited by the large quartzes in the same section.

A rock (1808) from the same belt of schists at a place in Upington Common, about eight miles north of the main road south of the granite kopje, is made almost entirely of quartz, felspar, sericite, magnetite, or ilmenite and sphene. Another rock (1809) taken from a spot a mile south of the last, forms part of a more felspathic-looking band lying in the quartz-schists. Under the microscope, it is seen to be a fine-grained rock, made of quartz, felspar chiefly untwinned, but some plagioclase is present, muscovite, chlorite, pseudomorphs often biotite, magnetite, apatite, and calcite. The chief constituents have a marked parallel arrangement. Much of the untwinned felspar is cloudy and contains small sericite flakes. This rock is evidently a fine-grained gneiss, and coarser gneisses were seen forming other bands in the schist belt in the neighbourhood.

This schist belt bordering the Upington granite is probably of various origins; some of the bands are almost certainly altered sedimentary rocks, and others are certainly gneiss of igneous origin.

The Upington granite area has been examined only in part. Like the smaller granite areas described above, it is the northern end of a large mass, extending into the Kenhardt Division. The width of that part of the area on the north bank is not known, but it stretches from Melkstroom beyond Upington village. The granite passes under unconformably overlying rocks between Christiana and the Hygap.

Generally the granite rock is covered by a coarse sandy soil, partly derived from the immediately underlying granite or gneiss. The more massive varieties occasionally form bold "tors," hills of naked granite, usually made of very large rounded blocks, separated by spaces, except at the points of contact. The spaces are due to weathering along joints, and the removal of the debris by wind and rain. There are several of these peculiar kopjes on Upington Common; a good example lies near the main road, through the south-eastern corner of the Common, and another close to the most used main road to Zwart Modder, nine miles out of Upington. They look as if made of blocks thrown down in a heap. On Blaauwbosch there are similar kopjes, and also remarkable boulders of great size left balanced on small surfaces.

Where the rock is well foliated, as in the immediate neighbourhood of Upington village, the kopjes assume a more ordinary form, for the rock weathers more uniformly from the exposed surface inwards, and the joints have not the same im-

portance in determining the incidence of the weathering processes as in the massive granite.

Depressions in the surface of the granite, due to the removal of the weathered debris, are not often seen in this area, but a well-known water-hole, about 10 miles from Upington, on the Zwart Modder road, is of this nature; it is a long hole, about 12 feet deep at present, and is due to weathering along a north-south joint. It is unlikely that a hole of this sort at the general level of the country would be hollowed out by the wind alone; as in the north of Van Rhyn's Dorp,[1] artificial excavation would seem to be necessary before the hole served a useful purpose, but I could not discover whether this water-hole had been dug out within recent years.

There are several varieties of granite in the surveyed part of the Upington mass. There are various gradations between a quite massive rock and well-foliated gneiss, and in composition the rock varies from a biotite-granite, with little or no hornblende, to a hornblende-granite, and there are also bands of hornblende—and pyroxene—granulite.

A specimen (1806) taken from one of the first massive-looking outcrops met with as one approaches Upington Common from the east is found, under the microscope, to consist of quartz, felspar, biotite, green hornblende, sphene, magnetite, and apatite. The structure is usually granitic without porphyritic constituents, but there is a considerable amount of micropegmatite, and also bands and patches of quartz-felspar mosaic. The felspar is chiefly microcline, but there is some untwinned felspar, which is usually cloudy, and contains much sericite. Neither the hornblende nor biotite form well-shapen crystals. The hornblende is a rather deeply coloured and strongly pleochroic green variety; the biotite is brown and strongly pleochroic. The sphene is in rather large, irregular pieces; it is twinned and slightly coloured and pleochroic. The magnetite and apatite are in small quantity. All the minerals are strained, but the hornblende shows less effect of the straining than the others. A fine grained, somewhat schistose, band traverses this massive rock, and in thin section (1870) it is seen to be made of pieces of quartz and felspar (microcline and acid plagioclase), set in a matrix of smaller fragments of the same minerals, together with some epidote. There are also fragments of magnetite, sphene, and apatite. The rock has a distinct banded structure, owing to the arrangement of the fragments, with their longer axes parallel. The band, which is evidently a zone of fracture, runs N. 25° W., approximately in the same direction as the strike of the nearest Kheis beds and their line of junction with the granite.

The prominent granite kopje, mentioned above, on the east side of the Common, is made of a rock which looks massive on

[1] See Ann. Rep. Geol. Comm. for 1904, p. 12.

the outcrop, but a parallel arrangement is noticeable in a thin section (1811), and the larger quartzes and felspars are cracked perpendicularly to this structure. The rock consists of quartz, microcline, orthoclase, biotite, muscovite, magnetite, or ilmenite, and very small quantities of zircon, sphene, and apatite. Much of the quartz and some felspar is in the form of a mosaic of larger-sized individuals than those of the mosaic in the crushed granite just described, but the mosaic is evidently the result of a similar process to that which gave rise to the crushed band. The biotite is in rather small irregular flakes, and is partly changed to chlorite. The muscovite is also in small flakes, and may perhaps be an alteration product.

The Upington kopje, on which a beacon of the geodetic survey stands, is made of various gneissose and banded rocks traversing more massive granite. The foliation and bands dip towards W. 20° S. The bulk of the ridge is a rock taken in the field to be a grey hornblende gneiss, but microscopic examination proves it to be an augite-granulite. The constituents (1812) form nearly equal-sized areas, and are always allotriomorphic; they are felspars, a green monoclinic pyroxene, and small quantities of quartz, sphene, hornblende, and epidote. Most of the felspar is plagioclase of a variety near andesine, but there is some untwinned felspar, cloudy with alteration products, amongst which sericite is the most abundant. The pyroxene is a green monoclinic variety, and is scarcely pleochroic; the prismatic cleavage is not well-developed. The hornblende is a green pleochroic sort, and has a well-developed prismatic cleavage; it is the same kind of hornblende as that seen in the hornblende schists or amphibolites of Gordonia, and it is not uniformly distributed through the rock, but occurs in some bands only. The epidote is chiefly found with the hornblende, but small quantities are in some of the felspars. Sphene occurs in grains without crystal faces. This rock is traversed by veins of hornblende granite, which is seen in thin section (1813) to be made of quartz, microcline, orthoclase, hornblende, sphene, and a little zircon and apatite. The orthoclase is cloudy, otherwise the rock is quite fresh. The hornblende is a strongly pleochroic green-brown variety.

Coarse pegmatites occur in veins traversing both the granulites and the granite veins.

A dark, well-banded rock (1814) from this ridge is found to be a hornblende—pyroxene—granulite, made of hornblende, monoclinic pyroxene, quartz, felspars, and a little sphene and epidote. The hornblende and pyroxene are the same minerals as are in the hornblende-granite and the pyroxene-granulite described above, but they are collected together in more or less definite bands, which give the rock a very dark colour. Much of the felspar is a variety near andesine, but there is some orthoclase, partly altered to cloudy sericitic patches, and there are also a few grains of microcline. Quartz is less abundant than the felspar.

On the left bank of the Hygap, on Ghous, just below the junction of the tributary from Grond Neus, there is a small inlier of granite and schist. (See fig. 1.) The granite is slightly foliated, and is seen under the microscope to be made chiefly of quartz, orthoclase, and brown biotite, with a small amount of repeatedly twinned plagioclase. The slice (1816) shows a pronounced parallel structure, which is at least partly due to crushing and a fresh development of quartz and felspar. The biotite is much bent and broken. All the constituents show optical anomalies, due to strain. The parallel structure runs N. 25° W., parallel to the bands and schistosity in the schists in the outlier.

The schists occur on the north-east side of the granite, and also as great masses in the granite, separated at the surface from the main mass of the schist. (See fig. 1.) They consist of quartzitic rocks, quartz-schist and sillimanite-schist. Two slices have been cut from the latter rock, and they show several interesting features. One section (1817) consists of quartz, garnet and sillimanite in abundance, and also red mica, white mica, felspar, magnetite, and pyrites. The quartz alone shows a distinct parallel arrangement, but other constituents, especially garnet, are cracked perpendicularly to the long quartzes; the quartz is much strained and broken, except those small pieces entirely enclosed by garnet. The garnet is pink in the hand specimens, but colourless and quite isotropic in thin section; it encloses portions of all the other constituents. There is a small amount of a deep green isotropic mineral, with as high refraction as that of the garnet; it is either a green garnet or, more probably, a spinel. The sillimanite is in fibrous masses and in large prisms; the latter are broken, and show irregular extinction; the mineral is scattered irregularly through the slice. The red, strongly pleochroic mica is in small flakes and aggregates; it often also fills cracks in the garnet, and lies parallel to the walls of the cracks; small round pieces are enclosed by the garnet. The felspar is much altered into a mass of sericite and zoisite, but parts show repeated twinning.

The second slice (1818) has the same constituents as the other, but they have a more pronounced parallel arrangement, owing to sillimanite, garnet, and some of the mica adapting themselves to the parallelism of the long quartzes. In this slice the colourless garnet is less abundant, and the green isotropic mineral much more abundant than in the other.

Granite and Associated Rocks of the Vryburg Division.

The granites and allied rocks of Vryburg are limited to the country north and east of the Black Reef escarpment, which trends westwards from near the town of Vryburg to Garophoane, on the Mashowing, and thence east-north-east through Morokwen.

Though this group of rocks is seen at the surface in many places, and has been met with in wells over a large area, it is frequently concealed under sand and other surface rocks. It differs chiefly from the Gordonia granite group in not having been found as an intrusion in older rocks corresponding to the Kheis beds of Gordonia, though further to the north-east some highly metamorphosed rocks, probably of sedimentary origin, were found associated with granite which is continuous with that under description.[1]

The Vryburg granite does not form prominent hills like those near Upington; only near the escarpment immediately west of Motiton were outcrops of considerable height seen, though along the Mashowing bed and in the Mokgalo, Kgogole, and Genesa laagtes occasional large bare surfaces of granite are exposed, and there are similar outcrops near the large pan on Morokwen.

The granitic rocks crop out occasionally in the Thlakgaming laagte, which passes through the eastern end of the Genesa Reserve. The upper part of this dry valley is called the Doorn laagte, and in it a few outcrops of massive pink biotite-granite appear, and weathered rock of similar character, though sometimes foliated, is thrown out from wells in the laagte. Near the Thlakgaming location, the granite contains enough epidote to give the outcrops a green colour. On Reitzdale the granite is weathered to a depth of 90 feet, as proved by the rock thrown from a well.

In the Genesa laagte gneiss and granite crop out occasionally. In one of the head valleys of this laagte, on the farm Boschbult, a well has been sunk 140 feet deep; the weathered granite was struck at 17 feet, and solid granite at 120 feet. The rock is partly gneiss and partly massive biotite-granite; coarse pegmatite veins traverse both varieties. A thin section (1718) from a granite shows this rock to be made of quartz, microcline, an acid plagioclase, orthoclase, biotite, muscovite, apatite, and magnetite. The structure is typically granitic. The microcline and plagioclase are the most abundant felspars. The muscovite and biotite are in small quantity only, and the latter is partly changed to chlorite. The minerals, especially quartz, show strain shadows. Another slice (1719) from a granite, taken from 20 feet down a well on Ganna Laagte, a neighbouring farm, shows quite similar characters.

The foliation planes of the gneiss near Genesa trend about N. 15° E., and there are coarse pegmatites traversing the rock.

For many miles south of the massive granite outcrops in the Morokwen pan the granite is concealed, but it has been struck in wells in the Pepani laagte about 9 miles from Morokwen. Near Mrs. McKee's house a well sunk 130 feet through a sandy surface rock did not reach the granite, but further south, in the laagte, granite was met with 50 feet below the surface, and the well was

[1] Du Toit, Ann. Rep. Geol. Comm. for 1905, pp. 209—213.

sunk 340 feet without entering other material. A specimen (1824) taken from near the bottom of this well is made of quartz, plagioclase, microcline, orthoclase, chloritised biotite, a little muscovite, magnetite, and a fair amount of calcite. The microcline is not abundant. The rock is a massive granite.

No outcrops were seen in the Matamatobo laagte, but large surfaces of massive granite and one gneiss outcrop were seen in the Kgogole laagte on Kgogole and Ophir. These rocks are traversed by many veins of pegmatite. The smaller veins, those not more than 12 inches wide, have a peculiar structure; the sides are lined with a coarse rock formed by large plates of muscovite and biotite up to three inches wide, standing perpendicularly to the walls, and embedded in a coarse quartz-felspar matrix, the few inches between the coarse mica rock are filled in with a granite of apparently the same nature as the enclosing rock, a medium-grained biotite-muscovite-granite.

Large outcrops occur on Tlaping, on the Mokgalo laagte.

Granite and gneiss frequently appear at the surface for some 20 miles below Motiton in the Mashowing valley, particularly within 300 yards of the river bed.

Throughout this valley the rocks are moderately coarse, but they are not porphyritic. Bands of gneiss are seen, but they do not seem to be separate intrusions, and pegmatites cut both granite and gneiss. The foliation of the gneiss strikes about N. 15° E.

Near Takoon, in the Motiton Reserve, a large part of the rock is a hornblende granite, made of quartz, acid plagioclase, a little orthoclase, a strongly pleochroic green hornblende, a little biotite mostly altered to chlorite, apatite and magnetite (1632). The untwinned felspar is much altered. Further down the valley near Motiton a specimen from which a thin slice was cut (1626) is made of quartz, microcline, orthoclase, repeatedly twinned acid plagioclase, chlorite after biotite, apatite, magnetite, and a little calcite. Quartz forms intergrowths with the three kinds of felspar. A band of pale granite traversing this rock is made of the same constituents (1627), but it contains no quartz-felspar intergrowths, and there is a fair amount of epidote.

A gneiss from Kobogo (1722) is composed of quartz, acid plagioclase, and orthoclase, which often form intergrowths, together with small amounts of biotite, muscovite, and magnetite.

HORNBLENDE-SCHISTS OF GARAPHOANE.

The granitic rocks were not seen below a point about five miles below Masilibitsani, from thence to Garaphoane the surface deposits conceal the underlying rock. At Garaphoane the Black Reef escarpment crosses the river, and on the right bank, the rocks below the quartzites are exposed for a short distance. The lower rocks consist of dark hornblende-schists or amphibolites, often with a strongly-developed parallel structure, strik-

ing about N. 10° E., and lying nearly vertically. The total thickness of schists exposed is about 1,200 feet. They are traversed by many veins of white quartz. The easternmost outcrops are very fine grained, almost black, fissile rocks, in which no constituents can be seen with the unaided eye. Under the microscope, the rock (1730) is seen to consist of very small irregularly-shaped fibres and plates of pale, scarcely pleochroic, actinolite, usually arranged parallel to one another or in feathery aggregates; these are set in a matrix of a colourless mosaic, apparently of quartz; the only other constituent recognised is magnetite in minute crystals. This rock is followed westwards by several hundred feet of a coarser schist, made largely of a more deeply coloured green-blue-yellowish pleochroic hornblende which is also more strongly birefringent than the paler mineral in the other rock (1729); the only other constituents are quartz and a small amount of magnetite. The westernmost outcrops, which are directly overlain by the Black Reef quartzites are coarser actinolite-schist; this consists chiefly of pale, slightly pleochroic actinolite, with a small amount of clear mosaic, probably of quartz, and a few grains of zoisite (1726). Much of the actinolite has a parallel arrangement, and none of it shows crystal outlines. Interbedded with these fissile rocks there are bands of black massive rock, with little or no tendency to split parallel to the prevailing strike of the schists. Under the microscope, this massive rock (1727-8) is found to consist of the same minerals as the schists, but without a parallel arrangement. The pale actinolite is in ragged pieces in a colourless matrix, which seems to be chiefly quartz, but quartz also occurs in much larger patches. No felspar was recognised, but there is some cloudy material associated with the small quartz mosaic. Zoisite and magnetite, or ilmenite, and leucoxene are also present.

The Kraaipan Series.

Rocks which must be placed in the Kraaipan series occur on the eastern side of the Motiton Reserve and the country east of it, and possibly also on the farm Clapham, near Garaphoane.

The Motiton occurrence is certainly a continuation of the strip of Kraaipan beds on Kameel Rand and Hamburg, described in last year's Report.[1] The rocks make a distinct ridge, trending east and west parallel to their strike, though they do not crop out frequently. On Waai Hoek, quartz-porphyries are seen at the surface, and less frequently the magnetic quartzites crop out. As on Kameel Rand, the soil on this ridge has a much deeper red colour than on the granite and volcanic rocks (Pniel group) to the north and south.

In the western corner of Waai Hoek some prospecting trenches have been cut, and they expose a succession of magnetic

[1] Ann. Rep. Geol. Comm. for 1906, p. 12.

quartzites, followed by three feet of quartz-porphyry, with another band of magnetic quartzites above it; then comes a considerable thickness of chloritic schists or phyllites, which are deeply weathered. All these rocks dip at about 45° slightly west of north. The junctions with the granite both to the north and south are hidden, but the latter rock crops out between this belt of schists and quartz-porphyry and a smaller one, which lies about a mile-and-a-half further south. The existence of the southern belt was only determined by the presence of a few outcrops along the road leading down the hill to the upper end of the Mashowing valley and the occurrence of a strip of deep red sand, which in this neighbourhood certainly indicates the presence of highly ferruginous rocks under the soil.

The magnetic schists seen are rather coarse rocks, containing much magnetite; they are distinctly banded and resemble closely some of the rocks in the Kraaipan series in Mafeking.[1] The quartz-porphyry is a pale pink or grey rock with quartz blebs and crystals, and a flow structure can be seen on the outcrops. Under the microscope (1720) the quartzes, passed through by the one slice cut, are angular and without crystal faces; they include small round patches of the ground mass. The ground mass consists of a micro-crystalline mixture of colourless minerals, amongst which quartz and muscovite can be recognised; no felspar was detected. A few flakes of muscovite are larger than the usual minute flakes in the ground mass. The structure of the matrix is microgranitic and no micropegmatite is visible.

Further cuttings in the northern belt, on Motiton ground, have been made since the locality was visited by me, but they have not been examined by the survey.

Lying in the sandy soil behind the Black Reef escarpment on Clapham, there are blocks of fine-grained banded magnetic quartzites too large and numerous to have been carried there. As the spot is at a rather low level it is possible that the fragments indicate the presence of an inlier of the Kraaipan formation within the Black Reef belt, but no outcrops were seen. On the other hand they may be ferruginous beds like those in the Black Reef series between Geluk and Zwart Fontein.

THE WILGENHOUT DRIFT SERIES.

For a distance of some 10 miles down the right bank of the Orange River below Sterkstroom there is a group of very varied rocks, which cannot at present be definitely assigned to any described series, though in some respects they closely resemble rocks found in the Kraaipan series of Mafeking. When I first

[1] See Ann. Rep. Geol. Comm. for 1905, p. 232.

saw them in the field, a striking but superficial resemblance to the Vaal River and Transvaal systems was at once apparent, and some of the differences from the normal types of the latter groups were attributed to the effects of earth movements; but at the time one very great obstacle to their correlation was obvious, viz., the question how the lavas and agglomerates of the Koras group, which seem to belong to the Vaal River system, could have escaped the effects of the earth movements which sheared the Wilgenhout Drift beds. Subsequent study revealed other dissimilarities from the Vaal River and Transvaal beds and resemblances to the much older Kraaipan rocks. As the beds occupy a larger area in the Kenhardt Division, which will probably be examined next year with the advantages gained by last season's experience and the results of microscopical investigation, it seems better to place them in a temporary group of their own than to assign them definitely to a position amongst the rock formations already described.

The Wilgenhout Drift beds are exposed between Sterkstroom and Leeuw Draai, but the succession is not a continuous one, for they are evidently traversed by a fault on Zwart Kop. (See figs. 3 and 4.) The structure of the area seems to be that of a syncline trending a few degrees east of north with a fault along the axis with downthrow to the east; the succession is more complete on the east than on the west of the fault. (See fig. 4.) On the east side the whole formation seems to be thrown down against the Kheis beds of Groot Drink along the Groot Drink-Sterkstroom fault, which trends about E. 30° N., but near the river there is a large mass of diabase (see p. 86) between the two formations. On the west side of the area the Wilgenhout Drift beds are again bounded by a mass of similar diabase, which certainly has not been affected by the earth movements that sheared the sedimentary rocks. Whether the boundary is a fault is not quite certain, but the straightness of the limit, which lies about north-north-east nearly parallel to the strike of the Wilgenhout Drift beds, gives it the appearance of a fault.

The lowest rocks assignable to the Wilgenhout Drift beds are some porphyries, the outcrops of which are meagre, so that their relation to the succeeding beds is doubtful. These rocks are dark greenish in colour, with white porphyritic crystals, which are as much as a third of an inch long. The matrix is fine grained. Under the microscope (1775), the porphyritic crystals are found to be entirely changed to sericite and other alteration products of felspar; they lie in a matrix made of augite, felspar and magnetite with a small amount of clear alteration products between them. The augite is very little altered; it is an almost colourless variety and never has crystal forms; it occurs in irregular grains and small ophitic plates enclosing wholly or partly very small laths of felspar; it has a basal striation slightly developed and is often twinned on (100). The felspar enclosed by the augite is the only felspar left unaltered;

it is a rather basic variety judging from the high symmetrical extinction angles in some twins. The magnetite crystals are

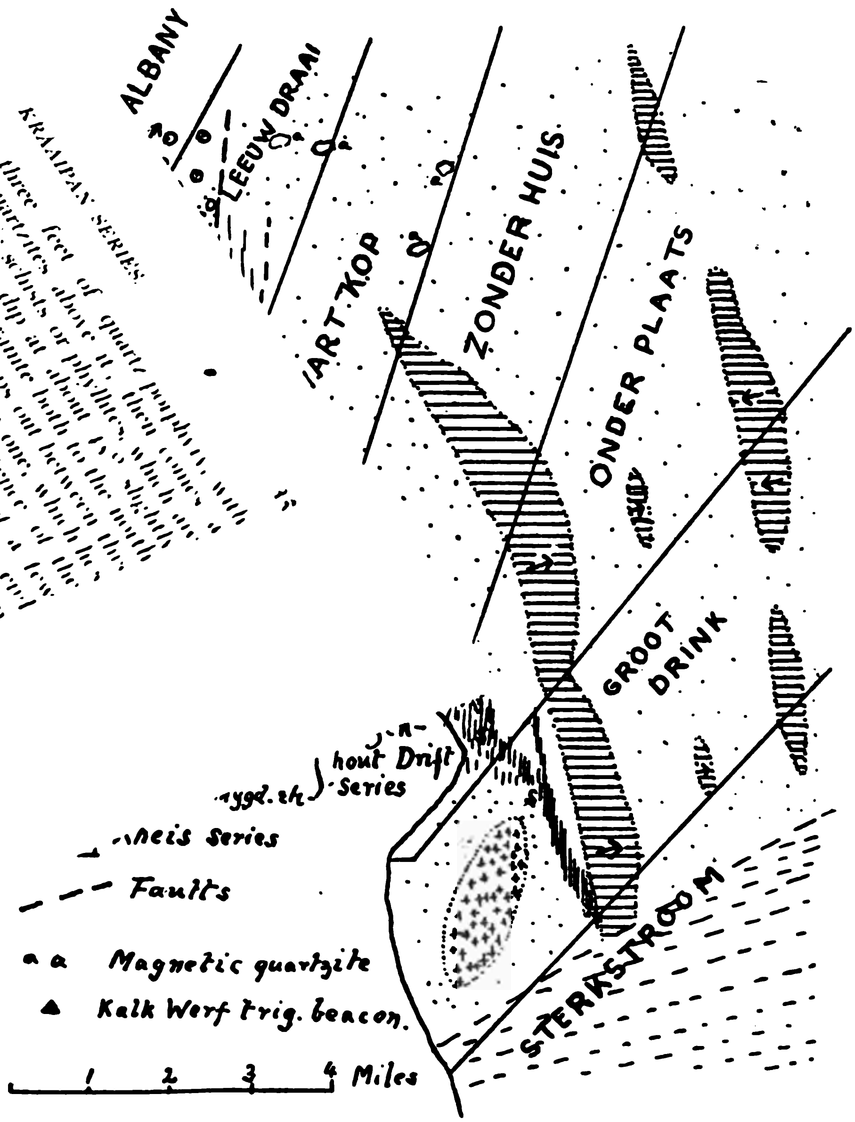

FIG. 3.—Plan of Wilgenhout Drift beds, etc., on the right bank of Orange River above Upington.

often arranged in two series of rows of octahedra, attached axially and crossing at right angles, as that mineral sometimes occurs in glassy basalts. The clear alteration products in the

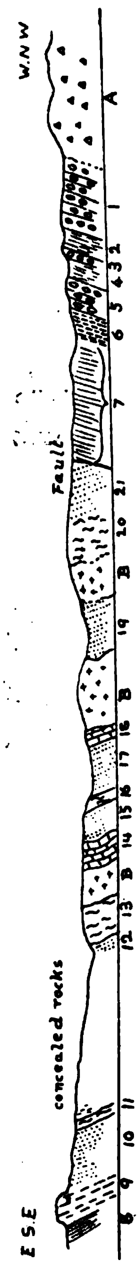

FIG. 4.—Section through part of the area occupied by the Wilgenhout Drift beds between the south-western corner of Zonderhuis and the diabase on Leeuw Draai—distance about 3,000 yards. A, intrusive diabase of later date than the cleaving of the Wilgenhout Drift beds; 1, amygdaloidal lavas and breccias; 2 and 4, slates; 3, conglomerate with green matrix; 5, amygdaloidal lavas; 6, slates, felspathic sandstones and quartz grits; 7, cleaved diabase tuffs and lavas, fault; 8, green phyllites of the S.W. corner of Zonder Huis; 9, red quartzites of Zwart Kop Kopje; 10, 12, 15, 17, 19, 21, grey tuffy beds; 11, 13, 16, 20, quartz-porphyries; 14, 18, limestones.

matrix of this rock probably represents a glassy base. This porphyry was only seen on Groot Drink, and its characters are so different from those of the lavas to the north-west that it is very doubtful whether it should be placed in the Wilgenhout Drift beds at all; but it is considerably more altered than the large diabase intrusions along the boundary faults though it does not show the effects of shearing that the Wilgenhout Drift lavas exhibit.

North-west of the porphyries there is a great thickness of green rocks, all considerably sheared; they include well-cleaved slates, amygdaloidal lavas and breccias containing lumps of the lava. In addition to these there are later intrusive rocks which, unlike the porphyry, have been sheared to the same extent as the sedimentary and volcanic rocks invaded. The intrusive nature of some of the green rock is obvious in certain places where the slates are penetrated by tongues of the former and contain flakes of mica within a few inches of the igneous rock, but not elsewhere (see fig. 5). The intrusive rock (1777) is made up of hornblende, quartz, ilmenite and leucoxene, sphene, epidote, chlorite, and a very little felspar. The hornblende is of two kinds, a green-blue, rather strongly pleochroic sort, in irregular plates which extinguish uniformly, and paler uralitic hornblende in fibres and aggregates. These two minerals made up the greater part of the rock; the quartz and other constituents form the ground mass, none of them have crystalline forms. It is possible that the larger plates of hornblende may be original constituents, but more likely that it is a fresh development like the other minerals, except ilmenite. The felspar seen does not look like original felspar; it is quite clear and in small grains, and is recognised by an occasional twin. This specimen was taken from the spot a in fig. 5; another slice from b (1778)

shows somewhat different characters, though it is is certainly part of the same rock mass from which the former came. The hornblende in the latter case is a very pale variety in elongated prismatic forms, which, however, do not show definite boundaries; these long hornblendes are to a considerable extent arranged parallel to one another, giving the rock a marked fissile structure. The rest of the rock is made of small grains of quartz and perhaps felspar, chlorite, and much ilmenite and leucoxene in short linear aggregates. A section (1779) cut from

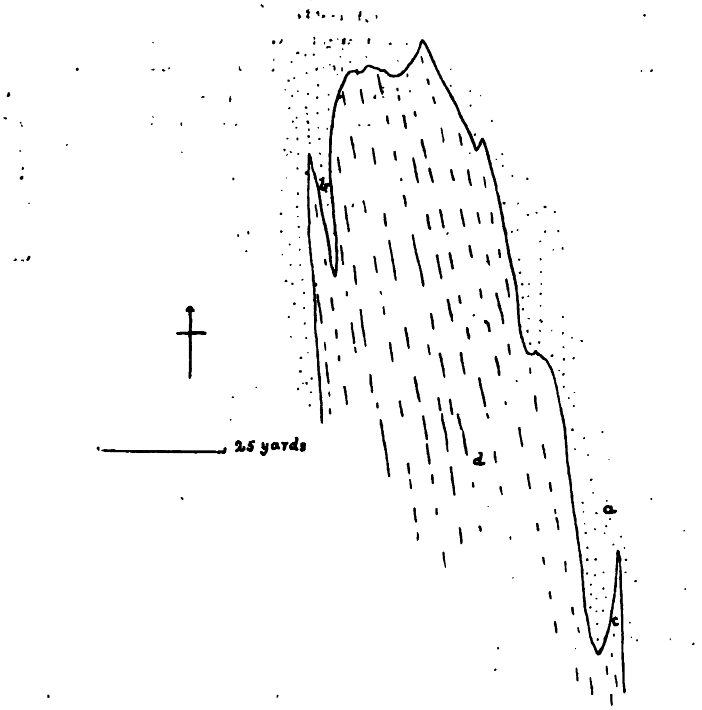

FIG. 5. Plan of epidiorite and slate contact on Onder Plaats.
a, *b*, Epidiorite; *c*, *d*, slates.

the sedimentary rock from within an inch or two of the epidiorite, at c in fig. 5, shows a base consisting of a colourless porcellanite-like aggregate, containing minute flakes of chlorite, some undetermined highly birefringent grains, and irregularly formed flakes of mica of a peculiar reddish yellow colour, but with the usual optical characters of biotite.

In isolated outcrops of igneous rock on Groot Drink and Onder Plaats, surrounded by alluvium, it was found impossible to decide whether the rock was of the nature of an intrusion or a compact lava. A dark greenish rock forming a band ten feet thick between green slates on Onder Plaats is seen under the

microscope (1780) to consist of large ragged plates of colourless tremolite, a considerable quantity of epidote in large irregularly-shaped grains, and large masses of leucoxene with a little ilmenite left, chlorite and a colourless aggregate of minute quartz grains and probably also felspar. This is a coarser grained rock than the intrusion described above, and from the large size of the leucoxene patches, the only direct representatives of an original constituent, it would also appear to have been an intrusion.

The volcanic rocks were recognised by the presence of amygdales, often elongated and distorted by shearing, and these amygdaloidal lavas are associated with tuffs and breccias. The volcanic rocks are green, often rather bright green, owing to the large amount of epidote in them. Two slices cut from amygdaloidal lavas on Onder Plaats show that the rocks have been very much altered; no sign of the original structure beyond the presence of amygdales is visible, the slices are made of irregular interlocking areas of epidote and quartz, containing a large amount of magnetite in small shapeless grains, sometimes collected in patches and enclosing the amygdales, which are patches of quartz and epidote free from magnetite. One of the slices has a fair amount of granular quartz mosaic and some calcite in small patches.

On the slight rise on which the Onder Plaats house is built, the volcanic rocks are well exposed. There is a thickness of over 1,000 feet of green amygdaloidal lavas and breccias, but their original nature is much obscured. Their structure is best seen on weathered surfaces where the amygdales, when present, are seen, but on a freshly-broken surface it is difficult to recognise amygdales in the elongated pale streaks and patches scattered through the rock. The nature of the breccias is also more obvious on a weathered than on a fresh surface. These rocks are traversed by veins containing quartz, calcite, and epidote.

The main body of volcanic beds on Onder Plaats is succeeded by a great thickness, 5,000 feet or more, of slates without lavas, but lavas and breccias like those on Onder Plaats appear again on Zonder Huis, where they are accompanied by green quartz grits and conglomerates with green matrix. The pebbles in the conglomerates are chiefly quartzite and quartz-schist. These are succeeded by some thousands of feet of soft and rather deeply weathered green phyllites, which are directly overlain by about 200 feet of dark red quartzites on the Zwart Kop boundary. The quartzites form the kopje from which the farm gets its name. They do not contain isolated pebbles or bands of conglomerate, and have a uniformly dark colour, except in a few bands, which are paler.

The red quartzites are followed by pale greenish tuffy rocks of a considerable thickness but not well exposed; outcrops of a very hard greyish white porphyry mark the presence of a thin flow of quartz-porphyry similar to thicker bands of porphyry

higher in the series. For a distance of some 500 yards north-west of this porphyry the rocks were not seen, but the soil contains fragments of greenish-grey tuffy rocks, above which are outcrops of similar beds; then comes the thick band of porphyry. This rock shows a flow structure in the arrangement of the porphyritic crystals (felspar and quartz) and fine lines in the ground mass. The rock (1782, 1783) has suffered from the effects of pressure and the porphyritic quartzes are granulitised. The felspar seems to be of two kinds, an acid plagioclase and orthoclase twinned on the Carlsbad law. The ground mass is made of a microcrystalline mixture of quartz and felspar with micrognanitic structure; there is also a fair amount of a rather highly refracting alteration product, which seems to be zoisite, sometimes partly replacing felspar crystals. Small veins of quartz and calcite traverse the slices. The rock is probably an acid lava; it resembles the quartz porphyry found in the Kraaipan beds of Waai Hoek.

To the north-west of the thick quartz-porphyries there is an intrusion of altered diabase, epidiorite, a dyke-like mass about 300 feet thick; two other intrusions of the same kind of rock occur further west, and from one of them a thin slice has been cut. The slice (1784) shows large and usually quite irregularly-shaped plates of colourless amphibole, probably tremolite, often deeply penetrated by the ground mass; occasionally prism faces and a pinacoid truncating the large angles made by the prism faces are developed. The rest of the rock is made of a confused aggregate of small flakes of tremolite, epidote, chlorite, quartz and perhaps felspar, and a considerable amount of leucoxene in rather large patches.

To the west of the first diabase intrusion there succeeds a band of marmorized limestone, or dolomitic limestone, about 100 feet thick, with which irregular layers of grey chert are associated. The limestone is in part soluble in dilute acid; it is white or very pale grey in colour, and has a saccharoidal structure. It has no close resemblance to the Campbell Road dolomites except to those parts of the latter formation within a few inches or a foot of a dolerite dyke. The saccharoidal character of the limestone in the Wilgenhout Drift beds extends throughout the limestone belts. This thick limestone is followed by some 3,000 feet of grey, ashy beds, with intercalations of quartz-porphyries, one limestone band and two diabase sheets (see fig. 4).

This part of the section terminates with some grey, ashy beds, which are limited by green cleaved tuffs and lavas probably lying on the upthrow side of a fault. West of this fault the strike is between north and east, and the beds are very similar to the green rocks on Onder Plaats and Zonder Huis. The diabase at the west end of the section has not been sheared, and is similar to that at the east end.

There may be repetition of beds due to folding in this section,

but the dips from the porphyry on Groot Drink to the fault on Zwart Kop are all westerly and at high angles.

Veins filled with quartz and red felspar occur in the green rocks west of the fault.

Between the western diabase and the next succeeding rocks, the Koras quartz-porphyries, there is a conspicuous belt of white vein quartz, probably deposited along a fault.

Four isolated kopjes of dark magnetic cherty quartzite occur to the north of main area of the Wilgenhout Drift beds, and are separated from it by several miles of low ground, on which fragments and a very few outcrops of green slates were seen; these slates must certainly be placed in the Wilgenhout Drift series, but their relation to the magnetic quartzites is uncertain. In the case of two of the kopjes, the supposed Matsap beds of the Onder Plaats ridge intervene between them and the nearest outcrops of the Wilgenhout Drift beds. The quartzites are black, dark brown or grey, and they may be matched by specimens from either the Griqua Town or the Kraaipan formation; but no rocks which are decidedly peculiar to one of these two formations were found amongst the quartzites. No thinly-banded rocks were met with; they are all rather massively bedded rocks, in which the layers of different colour and magnetite contents alternate in thicknesses of an inch upwards. They dip between N.E. and E.N.E. The strike is thus parallel with the strike of some of the Wilgenhout Drift beds, but in an area of great disturbance, such as this is, parallelism or divergence of strike is not of great importance in grouping isolated outcrops. On the whole, the occurrence of the magnetic rocks would seem to lend weight to the view that the Wilgenhout Drift beds, supposing these to include the quartzites, belong to the Kraaipan formation.

About five miles north-east from the Upington beacon there is a low hill of dark quartzites, about 700 yards long and 300 wide, trending W. 40° N., with synclinal dips up to 50°. The quartzites are dark brown, red and rarely grey, and they usually have a uniform texture like the Zwart Kop rock, but they are thinner bedded, and include some gritty bands with a few quartz pebbles. Below the quartzites and on the south-west side of them there are a few small exposures of a fine grained blue diabase or epidiorite, whose relations to the surrounding beds could not be ascertained. Though these quartzites present some points of resemblance to the Zwart Modder series described below, they are here placed with the Wilgenhout Drift beds, because they lie above the diabase and are much more sharply folded than the Zwart Modder beds in this district. This isolated mass of quartzite and diabase occurs amongst the grey quartz and mica-schists of the Kheis series, to which they offer a marked contrast; they must in any case be of much later date than the Kheis beds and the intense metamorphism exhibited by the latter.

THE ZWART MODDER SERIES.

North of Upington Common, as far as the Nossop, there is only one series of rocks intermediate in age between the Upington granite and the Karroo formation. These rocks are almost horizontal quartzites, sandstones, and shales, and they will for the present be called the Zwart Modder series, for they cannot be correlated definitely with any known formation. The outcrops of this series are separated from the nearest comparable rocks to the east by more than 100 miles of sand-covered ground, and the geology of the country south of the Orange River is too little known to allow a profitable comparison with the Ibiquas or the Nieuwerust series of Van Rhyn's Dorp and Calvinia. A comparison with the horizontally lying arenaceous beds of the Han Ami plateau[1] to the west, which have been referred to the Transvaal formation, does not aid us much, for the Zwart Modder group differs in many respects from the Transvaal formation as developed within Cape Colony.

The series consists of quartzites, sandstones, and shales, with a small amount of calcareous matter in them; no conglomerates were found, though the sandstones occasionally have a few isolated water-worn pebbles in them, but never in sufficient numbers to give rise to gravelly beds. The prevailing colour of the beds is red, though grey quartzites are occasionally seen, especially when the unconformable junction with the granite and schists is exposed, and again on a horizon about 500 feet above the base of the formation. Above this horizon the red beds become less frequent, and rather loose textured brown, yellow, or grey sandstones make up the bulk of the rock for a considerable thickness. What are probably the uppermost beds of this series seen during the last journey are blue-black shales with much detrital mica; the well-exposed beds of the Sannah's Poort hills probably lie below these dark shales, and they consist of thin sandstones and shales, red, pink, brown, grey, blue and green in colour. Throughout the series both ripple-marked and current-bedded rocks occur and clay-pellets are scattered through many layers of sandstone and quartzite.

Towards the upper part of the series the rocks are very like some of the Karroo beds, and where there is no direct evidence of the position of distinctive Karroo rocks, such as the Dwyka, in the neighbourhood, it is difficult to be satisfied to which formation certain beds in isolated outcrops or wells belong; for very similar sandstones and shales occur in Gordonia both above and below the great unconformity at the base of the Karroo series.

Except near Sannah's Poort, where the rocks form the south-eastern limb of an anticline trending S. 35° W. into German territory, they lie nearly flat, with perhaps a dip of less than 1°

[1] Schenck, Pet. Mitt., 1888, 225. "Die Geologische Entwickelung Südafrikas."

towards the north or north-east. Their thickness must be considerable, though it is at present uncertain. More than 1,000 feet are seen in the south-eastern limb of the Sannah's Poort anticline, and there are quite 500 feet of beds, probably entirely below those of Sannah's Poort, between Ghous and Bloemfontein; then again more than 100 feet of yellow sandstones and blue shales, probably above the Sannah's Poort horizon, occur between Haakschein Vley and the Molopo. So that the exposed thickness is likely to be 1,600 feet. Then there must be some rock with south-easterly dip hidden between the easternmost outcrops of Sannah's Poort and the westernmost rocks of Haakschein Vley, a distance of some 12 miles, and the formation is cut off above by an unconformity. So the total thickness of arenaceous beds and shales in the Zwart Modder series is likely to be considerably more than 1,600 feet.

Some doubtful quartzites on the Upington Commonage, which I have placed in the Wilgenhout Drift beds, may possibly belong to this group, but for reasons given on another page (p. 42), they appear to belong to the older series.

The first outcrops of undoubted Zwart Modder beds were seen on the western side of Areachap, forming part of an inlier of granite and quartzite, surrounded by the Dwyka series. The granite forms a low kopje, and on the south side of it there are thin red quartzites and micaceous shales, dipping at moderate angles south-eastwards away from the granite. About 100 feet of these rocks are exposed before they are covered by the Dwyka boulders' beds. The quartzites contain a few well-rounded pebbles of vein quartz and many mud-pellets, and most of the layers are ripple marked. The junction with the granite is not seen at the surface, though outcrops of the two rocks lie within a few feet of each other. The junction is certainly an unconformity, and not an intrusive contact. A small area of quartzites, lying eastwards of a low granite kopje, occurs in an inlier on the south end of Rooi Puts surrounded by the Dwyka. A larger inlier has been uncovered by denudation on Steenkamps Puts and Blaauw Bosch; a small inlier of granite projects through the Zwart Modder beds. The quartzites here are grey, red and brown in colour, and contain numerous clay-pellets, the weathering out of which gives rise to pitted surfaces on the quartzites. There are also some red micaceous shales. These rocks lie nearly flat, and often show rippled surfaces. A second patch of quartzites on Blaauw Bosch wraps round the western end of a hill of granite, which projects into the Dwyka area here.

In none of these localities where the basal beds of the Zwart Modder series are exposed is there any evidence for the intrusive nature of the granite with regard to that group, and the same statement holds good in the case of the Ghous granite inlier, so there is no doubt that the Zwart Modder beds are of much later

age than the granite. Another noteworthy fact concerning these basal beds is that they do not include any arkose (consolidated granite debris); in this respect they differ from the basal beds of the Black Reef series, where these lie directly on granite in the Vryburg Division, and also from the basal beds of the Nieuwerust series lying on granite in Van Rhyn's Dorp.

A large area of Zwart Modder beds begins on Grond Neus, and stretches down a tributary of the Hygap and up the latter river to a point above Bloemfontein, where the rocks are covered by sand and surface limestone. The southern limit has not yet been traced, but from the position of an escarpment marked on a map issued with the report of the Anglo-German Boundary Commission,[1] the series evidently passes into German territory a few miles north of the Aries (M line) beacon, about in latitude 28° 4′ south. Though the boundary has not been mapped, granite hills on Small Visch and Toeslaan are visible from high ground on Ghous. On Ghous the base of the series is seen wrapping round the small inlier of granite and schists shown in fig. 1. The lowest beds are thin grey rippled quartzites. The dips seen round the older rocks are local, and perhaps to be accounted for by very slight earth-movements, which produced a more noticeable effect immediately about the then buried inlier than further away from the same mass of old rock.

The Zwart Modder beds are magnificently exposed in the valley of the Hygap between Bloemfontein and Ghous. They form cliffs on each side of the river, which here occupies a gorge, up to 200 feet high. Owing to the low northerly dip of the beds and the rise of the channel northwards, higher and higher beds are met with as one travels up the river. The beds on Ghous and Zwart Modder are chiefly thin reddish quartzites and red micaceous shales, much like some of the Witteberg beds of the south of the Colony. The quartzites often contain mud pellets. The alternation of thick bands of shales with quartzites or sandstone beds gives rise to terraced slopes where the cliffs become less steep than usual. Occasional coarse gritty quartzites occur on Zwart Modder. In the higher beds on Zwart Modder and Zout Puts the colour of the sandstones is less frequently red than below the Zwart Modder store; the rocks are more often grey or yellowish. The shales become of less importance above Zwart Modder, where thin-bedded sandstones, usually quartzitic on their exposed surfaces, form banks 50 feet thick. The thick sandstones are false-bedded, and have mud-pellets in them; ripple-marked surfaces are not frequent in this part of the series.

A thin section (1819) of a quartzite from Zwart Modder is seen under the microscope to be made of quartz, which is by far the most abundant constituent, clouded felspar without twinning, microcline and plagioclase, also a small amount of muscovite and zircon. Some of the quartz grains are well rounded, but there

[1] Berlin, 1906, plate II.

are many angular chips. Spaces between the grains are filled with quartz, often in optical continuity with one of the neighbouring quartz grains.

On Bloemfontein the Dwyka series covers much of the ground, but the Zwart Modder beds lie at a shallow depth, and are met with in the wells; they are seen at the surface on the eastern half of the farm, and again just south of the Kalk Vley beacon on the western side. The rocks are red and grey sandstones, grey quartzites and red micaceous shales; they lie almost flat.

North of Bloemfontein, I did not see any outcrops of this series nor wells sunk into it, until I reached the Skuynskalk pan (Uitzak); all the exposed rocks belonged to the Dwyka boulder beds, the shales above those beds, or to dolerite intrusions in them; but from information given to me by farmers, it is probable that there are inliers of the Zwart Modder beds on Naauwte, and perhaps on other farms along the German border.

There are two wells sunk in the Zwart Modder beds on the north side of the Skuynskalk pan, 40 and 97 feet deep respectively; the rocks thrown out are yellow and grey sandstones and blue micaceous shales, which have a dip of 5° towards south-east. These wells are entirely surrounded by superficial deposits, and I was for some time in doubt as to whether the rock belonged to the Karroo or Zwart Modder formation, but on the north side of the Skuynskalk dunes and about two miles from the wells, the Dwyka series is well developed, and the boulder beds lie at a level which is certainly some few feet above the top of the Skuynskalk wells. In this area of Karroo beds there is a considerable thickness of thin papery shale of a type which has not been found in the Zwart Modder series, and plant fossils, amongst which *Glossopteris* was recognisable, occur in these shales. The sandstones and shales of Skuynskalk very probably lie below the Dwyka, and they do not contain fossils. The next outcrops are on the north side of Koppjes Kraal pan, between it and Haakschein; they are grey sandstones and dark shales. Along the eastern side of these large pans there are several outcrops. The most extensive series of exposures is at the north-eastern side of Koppjes Kraal pan, where there is a line of cliffs (Blaauwkrantz), with a maximum height of about 100 feet. The cliffs show a succession of thick bands of almost black micaceous shale with interbedded layers of sandstone, 60 feet thick in all, capped by 40 feet of superficial sands and limestone. The shales contain a few dark calcareous concretions. I was doubtful whether these rocks might not belong to the Karroo formation, but a search lasting more than an hour failed to bring to light a trace of fossils, nor are there any boulders along the eastern edge of the pan at the level of the Dwyka boulder beds west of the pan. Though the Dwyka was not seen in place at the top of the cliff, nor in the sand-covered country just behind it, some boulders of blue amygdaloid and

several small pebbles of chalcedony from the amygdaloid were found in the surface deposits at the top of the cliff. It is likely that these typical constituents of the Dwyka boulder beds in this region come from a mass of those rocks lying above the beds seen in the cliffs and in the high-lying sand-covered ground east of them. On the whole, the evidence is quite in favour of the cliff section belonging to the Zwart Modder series. The outcrops on the east side of Haakschein Vley are greenish sandstones and shales of the Zwart Modder series; they are parts of a buried escarpment, continuous with the Blaauw Krantz cliffs. In many places, however, the steep sand hills east of the vley completely conceal these rocks. The sandstones contain occasional round pebbles of quartz and mud-pellets. The shales are thin sandy rocks like some of the Sannah's Poort shales. Similar sandstones and shales occasionally form flat outcrops on the floors of the Haakschein Vley and Koppjes Kraal pan, and they occupy large areas immediately beneath the floors of those pans, for intersecting straight lines of a slightly darker colour than the enclosed areas are seen on the hard, sandy mud. The dark lines are from 6 to 10 inches wide, and run W. 20° N and S. 10° W. on Koppjes Kraal pan, parallel to joints seen in flat outcrops in the same pan. The dark marks are due to the upward creep of moisture along the joints. I scraped away the hard mud from a few such places, and found the shale surface from one to five inches below.

For a distance of some 12 miles along the German boundary, in the neighbourhood of Sannah's Poort (near Rietfontein), there are low hills made of sandstones and shales, which must belong to the Zwart Modder series. They are chiefly thinly-bedded rocks, red, pink, brown, blue, and green in colour, dipping at various angles from 15° to 60° towards E. 35° S. Rippled surfaces and mud pellets are abundant in the sandstones. The axis of an anticline forms low ground in German territory, and the north-western limb lies about four miles west of Sannah's Poort. More than 1,000 feet of rocks are exposed in the south-eastern limb of the anticline in the Sannah's Poort hills. The junction with the Dwyka series is exposed on both sides of the stream bed which traverses the Sannah's Poort hills, and is continued towards Rietfontein. The uppermost of the lower group are hard thin green shales, much broken up at the surface. On each side of the stream the exact position of the unconformity soon becomes obscured by surface deposits, but for some yards on the banks the grey-blue Dwyka boulder beds are seen lying on the broken shales, which have a south-easterly dip of about 20°.

Thin sandstones and blue micaceous shales belonging to the Zwart Modder series have been thrown out from a dry-well in the bed of the Hygap on Inkbosch Pan; and a low cliff of yellowish false-bedded sandstone on the left bank of the same river on Lieutenants Pan probably belongs to the same series.

No fossils of any kind were seen in the Zwart Modder series, though a considerable time was spent in looking for them in the favourable exposures.

In lithological character the Zwart Modder group does not resemble very closely any one formation which is well known in Cape Colony. In general appearance it often reminded me strongly of the Ibiquas series as seen behind Stinkfontein Poort in Calvinia, but that resemblance is due more to the horizontality of the beds and the alternation of harder and softer beds than to any very close lithological similarity between the two formations; in particular, no worm casts were seen in the Zwart Modder beds like those in the Ibiquas, and the latter are generally less micaceous than the former.

There is no special resemblance between the Zwart Modder and the Nieuwerust series, and the absence of arkoses from the basal layers of the former makes a definite dissimilarity between the two. Certain bluish quartzites, also, are rather characteristic of the Nieuwerust beds in Van Rhyn's Dorp, and nothing quite like them has been seen in the Zwart Modder beds.

The nearest outcrops of the Black Reef series are probably those on the Mashowing at Garaphoane, but they are not like the Zwart Modder beds. The latter are very much thicker than the former, and differ from them in colour and also in texture, especially in the lack of conglomerates. The presence of calcareous concretions in the shales of Blaauw Krantz may be thought to indicate the coming in of a limestone formation corresponding to the Campbell Rand series. If the Zwart Modder beds do belong to the Transvaal formation, a great change in its nature takes place between the Vryburg and Griqualand West area and the west of Gordonia. There is, of course, no reason why such a change should not have been brought about, but its assumption on our present information is hardly justifiable.

There is some resemblance to the Matsap series of the Langeberg, allowing for changes in the latter brought about by greater disturbance, due to earth-movements. The Lower Matsap beds, however, contain thin conglomerates not seen in the Zwart Modder group.

There can be very little doubt that the Zwart Modder series is part of the horizontally-lying formation which covers a vast area in German South-West Africa, including those parts of the central highlands of Namaqualand called the Huib, Han Ami, and Homs Plateaux. No complete account of the geology of that country has yet been given, but the writings of Schenck[1] and the more recent work of Schultze[2] contain valuable informa-

[1] Schenck, "Gebirgsbau und Bodengestaltung von Deutsch-Süd-West-Afrika." Verhandl., dis X., deutschen Geographentags in Stuttgart, 1903: also "Die Geologische Entwickelung Südafrikas," Pet. Mitt., 1898.

[2] Schultze, "Aus Namaland und Kalahari," Jena, 1907. See also Passarge "Die Kalahari," pp. 56 and 57, Berlin, 1904.

tion on the subject. The presence of dolomite or blue limestone on the top of the sandstones in the Huib and Homs Plateaux gave rise to the correlation with what is now called the Transvaal system, but more work will have to be done before that correlation can be accepted. In Schultze's book there are several good photographs ("Aus Namaland und Kalahari," pp. 149, 159, 555, Tap. VI. [Slangkop], VII. [lower figure]), of the horizontal sandstones, and they are evidently the same kind of rocks as those in the cliffs below Zwart Modder (a photograph of the Zwartputs [? Zoutputs between Zwart Modder and Bloemfontein] rock is given on p. 552 of the book). The descriptions of the rocks are in agreement with this view.

There is perhaps more reason to regard the Zwart Modder series as belonging to the Transvaal system than any other, but the evidence is not very strong yet. Very likely the survey of the country between Upington and Van Rhyn's Dorp will prove a correlation with one or other of the pre-Cape formations in the latter district,[1] or possibly with part of the Cape system.

Beyond furnishing good flagstones and in some places fencing poles, the Zwart Modder series has no economic importance. There are occasional small quartz veins, but nothing worth the attention of prospectors was seen.

THE VAAL RIVER (VENTERSDORP) SYSTEM.

Rocks belonging to this system take a very small part in the structure of the area under description. The westerly termination of the belt below the Black Reef escarpment in the Motiton Reserve was described in last year's Report.[2] The further examination of the Mashowing valley below Motiton did not reveal more outcrops of the Pniel beds, though a small patch was found on the Morokwen Reserve. The Zoetlief beds form an outlier in the Motiton Reserve and Glenred, but were not seen elsewhere.

Between the outcrops of rocks belonging to this system in Vryburg and the country along the Orange River, where the lavas and sedimentary rocks of the Koras group occur, there is a wide stretch occupied by later and older beds. This fact, together with the lack of fossils in these formations, would alone make a certain correlation difficult, unless the lithological similarity were very close. The rocks here included under the Koras series differ from the hitherto described lavas and sediments of the Vaal River system in important respects, but there is some reason for thinking that the Koras series may have been formed

[1] After writing the above, I find a short description of the nearly horizontal beds in German S.W. Africa by H. Lotz, in Monatsbizichte d. D. Geol. Soc., Nos. 8/10, 1906, in which it is stated that the sediments of the Plateaux are (1) Arkose, slates and quartzites of little thickness; (2) dolomites; (3) sandstones and shales. It is the third group in this succession that is probably represented by the Zwart-Modder series.

[2] Ann. Rep. Geol. Comm. for 1906, p. 15, etc.

at about the same time as the Vaal River system, though their identity has not been established. In this Report, therefore, the Kóras series will be placed as a distinct sub-group in the Vaal River system.

THE ZOETLIEF SERIES.

Though quartz-porphyries and some compact fine-grained flaggy beds referable to this series undoubtedly form a considerable outlier on the bult between the Glenred laagte and the main valley of the Mashowing, the rocks are rarely exposed. They crop out occasionally from under the pale-coloured sand which covers the rocks over so large an area in the north of Vryburg and Kuruman. The outcrops are chiefly on the slopes of the bult, though sufficient fragments occur on the surface of the bult to satisfy one that there probably is a continuous outlier several square miles in extent. Near Mathioane some fine-grained grey flags crop out, and above them lie quartz-porphyries, pink in colour. About three miles north of the store at Takoon, at the extreme southern end of the outlier, there are greyish pink quartz-porphyries. A thin section (1843) from one of these outcrops shows the rounded remnants of a few quartz crystals, which have been partially resorbed by the rest of the rock when it was fluid; the bulk of the rock consists of quartz and felspar, which interlock and enclose smaller indeterminable constituents. The felspar is crowded with decomposition products.

In the last Annual Report[1] a description was given of some outcrops of the Zoetlief beds on the farms Hartebeest Pan, Kaffir Pan, Klipfontein, and Schildpad Kuil, in Vryburg, but no thin sections of the rocks were then available. Three slices have been cut since then; two of them are from the Kaffir Pan rock. These (1634, 1635) show porphyritic crystals of quartz and felspars rounded, and, in the case of quartz, deeply corroded by the magma and containing patches of it. The felspar is partly orthoclase, but most of it is plagioclase of a variety near oligoclase. There are also a few pseudomorphs of chlorite and quartz mosaic after a ferro-magnesian constituent, possibly a pyroxene; those are also zircons and altered ilmenite; a small amount of epidote and calcite are present. The ground mass is a microcrystalline mixture of quartz and felspar.

The slice (1636) from a specimen from Schildpad Kuil shows rounded and corroded crystals of quartz and felspar in a peculiar matrix, which looks like that of the Kaffir Pan rock by ordinary light, but between crossed Nicols it breaks up into large interlocking areas of quartz and perhaps also felspar, enclosing indeterminable dusty specks. The quartzes are cracked, and sericite fills some of the cracks, which do not extend into the matrix, except in two cases of cracks filled with quartz mosaic

[1] Ann. Rep. Geol. Comm. for 1906, pp. 14 and 15.

and a yellowish substance. The felspars are considerably altered, but enough of the original minerals are left to show that they include untwinned and repeatedly twinned felspars. Calcite and sericite are present as alteration products. There are a few small patches of chlorite, without such definite form as in the Kaffir Pan rock. Some calcite is found in the ground mass.

THE PNIEL SERIES.

The country in which the Morokwen Reserve lies is mostly covered with surface limestone and sand, but sufficient outcrops were found to indicate the approximate positions of the boundaries between the Campbell Rand series and the Black Reef, and also between the latter and the westernmost granite of the south-eastern part of the Reserve. Between the Black Reef outcrops near the Cattle Post north-east of Karathiuse and the granite there are outcrops and loose lumps of blue amygdaloidal lava and of greenish flags that prove the occurrence here of a patch of the Pniel series, for they are like typical rocks of that series further south-east. The extent of the Pniel series in Morokwen has not been proved, but it cannot be very great.

The Pniel beds between Takoon and the neighbourhood of Vryburg were described in last year's Report,[1] but thin sections of the rocks were not then available. A few sections have now been cut and examined, and will be described here.

An amygdaloidal lava (1628) from the hill covered with native-built schanzes in the fork of the Mashowing, just west of Takoon (Ann. Rep. for 1906, p. 16) is a rock of the augite-andesite class. Porphyritic crystals of felspar and augite are set in a matrix of small felspars and interstitial, almost glassy, matter. The large felspars have been replaced by chlorite, calcite, and sericite. The augite is generally fresh; it is colourless, and usually in long sections; the cross-sections show both prisms and pinacoid faces or the latter alone; occasional twins on (100) are seen; there are also shorter crystals with end faces. There seems to be no augite in the ground mass. The ground mass consists of small felspars, often in twins, a variety near andesine, a small amount of quartz, magnetite, and chlorite, calcite, and epidote as obviously secondary products; there is also an obscure weakly polarizing substance, brown with dusty inclusions, taking the place of original glass. The amygdales are made of layers of chalcedony, calcite, chlorite, and an opaque earthy substance.

A section has been cut from a compact-looking blue "diabase" forming the Takoon beacon hill (Ann. Rep. for 1906, p. 17), the intrusive or volcanic character of which was not determined. The slice (1631) shows much colourless augite in large plates, often with crystalline boundaries, set in a ground mass of

[1] Ann. Rep. Geol. Comm. for 1906, pp. 15—19.

plagioclase, some augite, a little quartz, magnetite and ilmenite, and as alteration products epidote, calcite, and chlorite. The augite is often twinned on (100); the faces most often seen are prisms and pinacoids, but in some transverse sections only pinacoids are noticed; end faces are sometimes developed; the augite has a striation parallel to the base in some sections. There are a few large felspars, irregularly shaped and partly altered; they are not so frequent as in the schanz hill rock. The small felspars belong to the oligoclase-andesine group. The ground mass contains little or nothing that can be referred to glass or its alteration products. No amygdales are seen in this rock.

A slice (1629) cut from the intrusive rock between the Black Reef quartzite and the granite south of Takoon (Ann. Rep. for 1906, pp. 16-17) presents some peculiar features. It is a dioritic rock with much micropegmatite. Hornblende is present in abundant large often ill-defined plates, sometimes penetrated by felspars; it is partly bounded by crystal faces, prisms and pinacoids, and it is often twinned on (100); it is strongly pleochroic (X pale yellowish Y rather bright green, Z blue green). The felspar is much decomposed, but an acid plagioclase, with refractive index less than that of quartz, is visible, and there is also untwinned felspar, presumably orthoclase, forming micropegmatite with quartz; micropegmatite forms a large part of the ground mass. Magnetite and ilmenite are present, and also chlorite, epidote, and calcite, as alteration products.

An amygdaloidal lava from Harbro (1633) contains no large porphyritic constituents. The amygdales are of quartz and chlorite; they lie in a fine-grained matrix of small felspars, quartz, magnetite, chlorite, and opaque dusty matter. The felspar is only partly unaltered, often in single twins with low extinction angles. The quartz is in small interstitial patches. The chlorite is in small patches, many of which evidently represent original grains of augite, for some have the octagonal shape of augite sections bounded by prisms and pinacoids; in some cases they are surrounded by minute opaque grains, probably magnetite. Chlorite also forms very slight plates, giving short needle-shaped sections.

THE KORAS SERIES.

This name is proposed for some quartz-porphyries, amygdaloids of more basic composition, conglomerates and sandstones seen on the right bank of the Orange River above Upington. The greater part of the conglomerates and sandstones is of later date than the igneous rocks, for fragments of the latter are the most conspicuous constituents of the conglomerates, but in some places there are fragmental rocks similar in character to the later ones interbedded with the lavas. These rocks taken together form a group distinct from all others in the district; they are all red or purple in colour, and nothing quite like them is known

to me from any other part of the Colony. Though there are certainly two or more unconformities within this series, the members of it seem to be so closely related that it would at present introduce unnecessary complication to divide the group up into formal sub-divisions.

So far as the examination of the Koras series has yet been carried, the lowest rocks in it are either quartz-porphyries or amygdaloidal lavas of more basic composition, and fragmental rocks of the nature of tuffs made of fragments of the amygdaloidal lava. The conglomerates and sandstones lie above these igneous rocks.

The series occurs in two rather large areas and two smaller ones. The largest area extends from Leeuw Draai on the east, where it is probably faulted down against the Wilgenhout Drift beds, and Koras-Uizip-Kameel Poort on the west, where it is faulted down against the Kheis beds. The distance between these faults is about 14 miles in a straight line measured near the Orange River, but as the eastern fault trends a few degrees east or north and the western one about north-west the area occupied by the Koras beds widens northwards, where it is buried under the red Kalahari sand. Along both boundary faults there are masses of a rock called diabase in the field, but which proved to be a doleritic rock, with some altered rhombic pyroxene and much devitrified glassy base; both intrusions are very similar rocks to that forming the Groot Drink mass, which also occurs along a fault (see p. 36).

The other large area is that of Rooi Kopjes, Rouxville and Uap, where there are amygdaloidal lavas resting unconformably, and apparently but little disturbed, upon the Kheis beds. Two small outliers were seen on the Kheis beds on the southern corner of Koras and on Rouxville.

On the farm Leeuw Draai a wedge-shaped strip of porphyry and amygdaloid, about a mile wide near the river, and thinning out towards north-north-east, separates the mass of intrusive dolerite mentioned above from the conglomerates and sandstones seen on Albany and also on Leeuw Draai. The disappearance of the igneous rocks towards the north is partly due to their having been cut out by the fault, for their strike is generally north-east, while the fault trends nearly north; there is also an unconformity above them, and this certainly contributes to their disappearance at the present surface.

The porphyry is a red rock containing crystals of felspar, quartz and a pegmatitic intergrowth of the two. Under the microscope the matrix (1846) is seen to consist of rather large irregularly-interlocking areas of quartz and felspar, crowded with dusty reddish matter, which evidently gives the characteristic colour to the rock, and a few flakes and grains of chlorite and epidote. The quartzes are chiefly well rounded and sometimes deeply corroded, but they occasionally have traces of crystal faces; the larger individuals are cracked, and the cracks,

which do not extend into the matrix, are filled with calcite. The felspars are similarly corroded; they are orthoclase in carlsbad twins, alone or intergrown with quartz; there is also a twinned plagioclase of a kind near oligoclase. There are also pseudomorphs of chlorite and epidote after a pyroxene which had more perfect shape than the other minerals. These pseudomorphs, which are of smaller size than the quartz and felspars, are often grouped together with magnetite and apatite. The rounded pegmatites are as much as an inch in diameter. and, in conjunction with the general appearance of the rock, distinguish it at a glance from any other quartz-porphyries known in Cape Colony

On Leeuw Draai this porphyry occurs in layers several feet thick, interbedded with the amygdaloidal lava, dipping north-westwards under the Albany conglomerates. The amygdaloid is a red or purplish rock with many amygdales of quartz and epidote. There are no porphyritic constituents, though the larger felspars reach the length of half a millimetre. The fel-spars (1786) are quite fresh, in lath-shaped sections, and have symmetrical extinction angles up to 18° or 20°, so they are of a composition between andesine and labradorite. The base in which they lie is a devitrified glass containing magnetite crystals, arranged in intersecting lines like skeleton crystals, and grains of a rather highly refringent and bi-refringent mineral which is probably epidote. There seems to be a little quartz, but most of the glass has given rise to aggregates of weakly refracting minerals of uncertain nature. There is enough haematite to colour the rock red, seen in thin sections clustering round the felspars. No pyroxene or recognisable pseudomorphs after it or another ferromagnesian mineral were seen. There are layers of red agglomerate and fine-grained tuffs interbedded with these lavas, and they contain abundant fragments of the amygdaloid.

No further outcrops of the amygdaloidal lavas were met with between Leeuw Draai and Kameel Poort or Koras, but quartz-porphyries form two very prominent kopjes projecting from the sand on Koras, about eight miles from the river, and from these kopjes three other similar hills are visible towards the north-east from two to six miles distant, but these were not visited. The rock is of essentially the same nature as the Leeuw Draai porphyry. A thin section (1787) shows that it is made of two kinds of rock, the major part is a porphyry quite like that of Leeuw Draai, with, however, some zircon crystals in addition to the constituents seen in that rock; this contains irregularly-shaped rounded masses and elongated streaks of a darker material made of precisely similar minerals as the other, but the quartz and felspar occur in chips, small fragments of crystals with sharp edges; the matrix of the darker rock is rather finer grained and contains more of the red, dusty matter than that of the rest of the rock. No amygdaloidal lava nor sedimentary beds were found either on or in the immediate

neighbourhood of the kopjes. Though one of the hills rises about 150 feet from the sand, no divisional planes that could be looked upon as separating distinct lava flows were found; the rock seemed to be uniform throughout, and it is traversed by .egularly placed joints which have allowed the rock to weather into huge rounded blocks that ring like metal when struck. The kopjes look as if they were made of boulders not less than six feet in diameter piled together. The debris from the weathered rock between the blocks has usually been removed by wind and rain, and as far as I could creep between the boulders into the hill no rock undoubtedly *in situ* was to be seen. The general aspect of these hills is exactly like that of the granite "tors" on Upington Common, described on a previous page.

Though no definite evidence of the intrusive nature of the quartz-porphyries on Leeuw Draai was obtained, the appearance of the rock there, and especially in the Koras kopjes, would indicate that it is intrusive.

The nearest exposed rocks in the neighbourhood of the kopjes are red sandstones seen about a mile to the south, dipping 45° to S. 10° W.

The conglomerates and sandstones cover an almost continuous area, 14 miles in length, between Leeuw Draai and the fault on Koras and Uizip. Towards the north they are covered by the red Kalahari sand, which extends in the form of long dunes to the river at several places; an especially broad strip of dunes is found at Kalk Punt.

These beds lie unconformably upon the lavas of Leeuw Draai. They are very frequently exposed for short distances, but their dips vary greatly in direction and amount. Dips as high as 50° were recorded, but they are usually lower than 20°, and they are most often towards the north, between north-northwest and north-east.

The sandstones are dark red rocks, often rather loose in texture, but they include many quartzitic layers. They are as a rule obviously felspathic, and, from the abundance of pebbles of the red porphyry and amygdaloid throughout the conglomerates, and of reddish granite and gneiss in some parts, it is evident that a large part of the sandstones and conglomerates was derived from such rocks. The conglomerates occur throughout the sedimentary part of the Koras series; in places they were seen to form lenticular beds a few feet thick and 100 yards or less in length along the outcrop. In many bands the matrix is soft, so the boulders and pebbles have weathered out and cover the ground over wide areas just as in the case of the Enon boulder beds in the south of the Colony. The pebbles are of all sizes up to two feet in length, and are almost always well rounded. Many of them are fractured, either along parallel planes or radially about a small indentation caused

by pressure from a neighbouring stone. The segments of fractured boulders are often shifted slightly relatively to each other. Circular rings or simple shallow depressions, not connected with any fractures, are seen on the surface of some of the pebbles, like those found on some pebbles in the Pokwani conglomerates.[1]

The materials making the pebbles are red quartz-porphyry, red and purple amygdaloid, whitish quartzite, granite, gneiss, quartz-schist, mica schist, and vein quartz. A careful search failed to reveal a fragment of blue or green slates or lava, dolomite, white quartz-porphyry or magnetic and red quartzite, such as might have come from the Wilgenhout Drift series. Towards the west granite pebbles became more abundant than they are in the eastern part of the area, though even in the west they do not occur so plentifully as the quartz-porphyries. There are many layers of gravelly conglomerates with pebbles not exceeding an inch or two in diameter. In many of these conglomerates the pebbles and boulders are closely packed.

A remarkable feature in the sandstones is the almost complete absence of current-bedding even in the thicker layers.

Towards the intrusion on Koras, the sandstones and conglomerates become much hardened, and, as a rule, darker in colour. Four slices were cut from specimens taken from distances of 40 yards and less from the dolerite outcrops. The rock at 40 yards from the igneous rock consists (1788) of many small quartz grains, evidently of detrital origin, embedded in a mixture of secondary minerals, quartz, epidote, and calcite. The original quartz grains are clear angular or sub-angular fragments, and the secondary minerals are mostly crowded with minute dusty inclusions, but there is some clear chalcedonic or quartz mosaic. The second slice comes from a spot about 20 yards from the intrusion, it (1789) shows clear quartz grains surrounded by large areas of cloudy quartz in optical continuity with the grains. The epidote is in much larger grains than in the last rock and contains less inclusions. The rock consists almost entirely of those two constituents, the only other constituents being opaque whitish and reddish substances. The third slice (1790) came from within 10 yards of the intrusion; it is very like the last, but the epidote is frequently in crystals. The fourth (1791) came from a mass of grit enclosed by the intrusion; it consists of a coarse quartz and oligoclase grit with fresh development of epidote and quartz. The oligoclase is evidently in original grains and has not suffered any appreciable change; there is a fair amount of quartz-mosaic. At the junction of the igneous and sedimentary rocks there is much fine-grained epidote-quartz-calcite rock (1795) of uncertain origin, and patches of a very similar rock are seen within the sedi-

[1] Ann. Rep. Geol. Comm. for 1906, p. 100.

mentaries of more usual character; the epidote rock may be an altered sediment.

On Kameel Poort there is a small mass of amygdaloid lying in a deep hollow near the north-eastern end of the Uizip beacon hills which are made of Kheis beds. Whether it is continuous with the large outlier to the west round the north end of the hills is uncertain as the ground is covered with superficial deposits. The amygdaloid lies near a steep wall of quartzite on the south-west, and is separated from it by a fine-grained siliceous and epidotic altered rock, probably an altered part of the lava, and by a few feet of breccia of quartzite fragments from the wall rock in a red siliceous base. The amygdaloid (1797) at this locality is like that of Leeuw Draai. The amygdales are of chalcedonic silica, epidote and chlorite, and they lie in an originally glassy matrix crowded with fresh felspars of the andesine group and small masses of magnetite, and also crystals of magnetite arranged in rectilinear intersecting rows; the base is almost opaque owing to the amount of red dusty inclusions and occasional transparent red flakes of haematite. No augite or other ferromagnesian mineral is present, but there are grains of epidote in the matrix. There are also patches of chalcedonic silica taking the place of some of the usual brown base in the interstices between the felspars. The hard siliceous rock between the amygdaloid and the quartzite (1798) shows no structure like that of the amygdaloid; it is made entirely of quartz, epidote, and calcite. The most of the quartz is in very small veins traversing a granular aggregate of the other minerals. The ordinary colourless and yellow pleochroic epidote often forms crystals projecting into the quartz veins. Much of the epidote is a peculiar variety which has not been seen in the other epidotic rocks of this district; it is a pleochroic pink mineral like piedmontite (X colourless to bright yellow, Y pink, Z deep pink). There is also some magnetite and much dusty opaque red matter, which gives the rock its colour as seen in mass.

It seemed to me that the Kameel Poort outcrops may mark the position of a vent, whence some of the volcanic rocks were ejected.

The large outlier covers about 10 square miles and passes under sand to the north-east. It lies in a wide hollow in the Kheis beds. The peculiar appearance of the well-rounded hills, in marked contrast to the sharper outlines of the hills made of the Kheis quartz-schists, has given the name Rooi Kopjes to one of the farms on which they occur. No fragmental rocks were seen in this outlier, and only very obscure divisional planes could be seen in the lava, the total thickness of which must be over 200 feet. Two slices were cut from the lava on Rooi Kopjes. One of them (1800) shows an almost opaque red ground mass, evidently once a glassy base similar to that of the Leeuw Draai rock, crowded with felspars of the andesine

series, of which some only are still fresh, and containing a few pseudomorphs of epidote and a serpentinous mineral, probably after a rhombic pyroxene. The other slice (1799) is from a rock of similar type but greatly altered by the conversion of all the felspars into aggregates of quartz and epidote; this slice shows more of the pseudomorphs after the supposed pyroxene; remains of the rectilinear groups of magnetite crystals are seen in the once glassy base. The amygdales in both these specimens are of epidote and quartz.

The rocks of this inlier seemed to be more generally epidotised than the Leeuw Draai lavas, and they have a very conspicuous and characteristic appearance owing to the abundance of bright green amygdales in a deep red or purple matrix; the purple colour is evidently due to the close intermingling of the red iron oxide and yellow or green epidote in the rock.

It will have been seen from the foregoing description that the Koras beds differ considerably from the known rocks of the Vaal River system. Their field relations to the Kheis beds are clear, the latter are very much older than the former, which rest upon them. It is also very probable that the Koras beds are much younger than the Wilgenhout Drift beds. If the suppositions, first, that the Koras beds belong to the Vaal River or Ventersdorp system, and, secondly, that the rocks of the Groot Drink hills are of Matsap age, are correct, the disparity between the changes in them wrought by pressure and earth-movements has to be explained. It may be that the down-faulted Koras beds lay just beyond the western limit reached by those changes. On the other hand, there is no good reason for excluding the possibility that the Koras series may be of later age than the Matsap beds and the movements that affected them. That the Koras series is of pre-Karroo age is extremely probable, for the Karroo rocks in that region, so far as known, have not been disturbed so much as the Koras beds. It cannot yet be said that fragments of the Koras beds are known from the Dwyka conglomerate.

THE TRANSVAAL SYSTEM.

Rocks belonging to this system have not been definitely recognised west of the Langeberg-Korannaberg range. The view expressed by Penning[1] that these rocks should reappear in the Kalahari has not been confirmed in the southern part of that region; at the same time there is room for the occurrence of one or more members of the system under the sand south of the Molopo, and, as noticed previously, it may be the case that the system is partly represented by the Zwart Modder series.

[1] Penning, gold and diamonds, London, 1901. Also in Wilkinson's "Notes on a Portion of the Kalahari," Geographical Journal, 1893.

The Black Reef Series.

This group was followed from the neighbourhood of Takoon down the left side of the Mashowing, where it is largely hidden under sand, and across the river at Garaphoane, where it is again concealed by sand. It was seen again on the Morokwen Reserve.

South of Motiton, the Tong Valley fault, which has a north-westerly course, displaces the beds so that on the upthrow (north-east) side they stretch at the surface much further south, owing to their low dip, than on the south-western, or downthrow side.

For a distance of some 12 miles between Zwart Fontein and Geluk there are some beds of a type not usually met with in the Black Reef series lying nearly at the top of it. They are ferruginous clayey sandstones and shales and cherty rocks, yellow and brown in colour, containing some magnetite. They give rise to a belt of rising ground called the Zwart Rand. They are probably about 80 feet thick. The cherty rocks are very like the more massive jaspery rocks of the Griqua Town series. It is possible that the fragments of magnetite quartzites found behind the Black Reef escarpment on Clapham, referred to on a previous page as possibly indicating an inlier of the Kraaipan series, may belong to a similar band to the Zwart Rand beds; but the fact that they occur in a depression is rather against this view. Similar rocks were not found in a corresponding position south of Motiton and Takoon, nor have they been recorded from the Black Reef series nearer Vryburg.

The Takwanen inlier, mentioned in last year's Report,[1] is an oval area of quartzites, thin dolomitic limestones and some volcanic rocks. The Lochnagar fault and dyke traverse its longer axis, but die out north of the Takwanen boundary. The inlier is thus a faulted anticline. The dips are very low, which makes the small thickness of beds involved occupy a rather large area. The lavas and tuffs all belong to the volcanic rocks lying near the top of the Black Reef series on the Vryburg escarpment. The lavas of the Pniel group at the base of this escarpment are not brought to the surface in the inlier.

A section seen along the river through Takwanen gave the following figures:—

Campbell Rand series at the top.	
Blue amygdaloidal lavas and blue-green flaggy tuffs,	15 ft.
Blue dolomitic limestone,	8 ft.
Blue amygdaloid and flaggy beds,	30 ft.
Blue dolomite,	5 ft.
Flaggy beds passing below into grey quartzites and grits, the usual type of quartzite of the Black Reef series in this neighbourhood,	50 ft. seen.

[1] Ann. Rep. Geol. Comm. for 1906, pp. 22—23.

The flaggy beds in this section are strongly ripple-marked.

On Garaphoane the series is exposed on each side of the Mashowing for a short distance. It there consists of quartzites and conglomerates. The pebbles are chiefly of quartz, but banded black and white cherts, green chloritic rocks, quartzites, dark slates, and some schistose magnetic rocks occur. The quartzites are false-bedded, and ripple-marked surfaces are often seen. They dip westward at low angles.

On Morokwen the series is poorly exposed, but the outcrops and a slight rise marking their position are sufficient to show that the Black Reef beds trend north-eastwards through the Reserve.

The Campbell Rand Series.

The Kaap Plateau, which is made almost entirely of these rocks, was crossed between Vryburg and Takoon; nothing of particular importance was met with, no fossils were found in the rocks. On Armoed's Vlakte near Vryburg a rather peculiar looking rock was seen above the highest beds that could be placed in the Black Reef series. It is a gritty rock, which weathers with a brown scoriaceous-looking surface; in thin section (1713) it is seen to be a gritty rock, with much calcite or dolomite. The gritty constituents are chiefly quartz, but there are also fragments of felspar and a few small pieces of a felspathic igneous rock that may have come from the Pniel lavas or intrusive sheets associated with them. Deposition of quartz has taken place round many of the quartz grains, and there is also some chalcedonic silica. The carbonates form grains and rhombohedral crystals in the rock matrix, and also oolitic grains, of which the original concentric structure is usually only visible by ordinary light, owing to its partial obliteration by subsequent crystallization of the carbonates.

The plateau formed by this series is about 62 miles wide near Kuruman, but decreases to 24 miles west of Garaphoane, where it is crossed by the Mashowing. Northwards it maintains about the same width as far as Morokwen. Penning evidently noticed this fact, and attributed it to the thinning out northwards of the dolomites.[1] No definite evidence for this statement has been brought forward, and the rocks are so much concealed throughout the area that in the absence of deep bore-holes the facts are difficult, if not impossible, to obtain. The dips are everywhere low, and there may well be undetected faults and gentle folds which greatly increase the width of country occupied by this group in the plateau.

The dolomites and cherts are only seen along the Mashowing for a distance of about half a mile some four miles up the river from Piet Quane (Derwent on the Divisional maps). The rocks

[1] Penning, quoted in Wilkinson's paper cited above.

are blue crystalline dolomites, with a few chert bands in them, very like many outcrops between the Mashowing and the Orange River. North of the Mashowing no outcrops were seen near the road between Heuning Vley and Morokwen; sand and surface limestone cover the rocks completely. South of the Mashowing no outcrops were seen within five miles of the hills formed by the Griqua Town series for some 15 miles south of Piet Quane, but the dolomites and cherts appear frequently on Kooroon and Gamolilo, and further away from the hills on Foster and Padstow.

West of the Kuruman hills in this region outcrops are exceedingly scarce, and there was no evidence found to indicate the extension of the Maremane anticline as far northwards as the Kuruman River.

In the middle of the scattered ranges known collectively as the Korannaberg there is a ridge, about four miles east-north-east of the watering-place called Blaauw Krantz, made of a mass of Griqua Town beds occupying the axis of an overturned anticline in the Matsap series. On the east side of the ridge, in a small kloof, there is a much broken but thick band of dolomite, which seems to dip at high angles westwards under the Griqua Town beds. It is a blue and grey rock generally, but there are reddish streaks in it, and also some dark cherts. This is the most westerly outcrop of the Campbell Rand series yet seen in Bechuanaland.

THE GRIQUA TOWN SERIES.

In this district the Griqua Town beds were only seen in the Kuruman-Heuning Vley hills and the country to the west of them.

(a) The Lower Griqua Town Beds.

These rocks form the Kuruman-Heuning Vley hills, an escarpment rising from the Kaap Plateau and limiting it on the west. For some 12 miles south of the gap cut by the Kuruman River the hills trend north-west, but between the Kuruman and Mashowing Rivers the trend is about N. 10° W. North of the Mashowing the rocks are very little exposed for some distance, but the position of the low hills made by the Lower Griqua Town beds on Dutton indicate a nearly northerly strike. North of the gap by which the conjoined Kgogole and Mokgalo laagtes pass through the belt of Lower Griqua Town beds, the general trend of the latter and of the hills formed by them is about north-north-east past Heuning Vley. I was on the hills some four miles north of Heuning Vley, and they are continued in a group of low hills for several miles further towards the north-north-east, then they apparently break off and reappear again at Skelek.

The dips are everywhere low, and are directed chiefly towards

the west. Near Heuning Vley, where the exposures are better than usual, low anticlinal flexures with axes at right angles to the trend of the hill are seen on the eastern slope of the escarpment; their effect is to give a slightly-arched shape to the beds outcropping on a long uniform piece of the slope. At the base of the escarpment at Heuning Vley, where it forms several low krantzes rising immediately from the floor of the pan to a height of 20 feet or less, there are some rather sharp corrugations affecting small thicknesses of rock. These are very similar to the less pronounced of the disturbances seen at the base of the Lower Griqua Town beds further south,[1] and they probably may be attributed to a similar cause, viz., the solution of the underlying limestone and dolomite and the settling down of the base of the Griqua Town beds No outcrops of the Campbell Rand beds were seen near Heuning Vley, but from the sudden change in the topography at the base of the escarpment and the abundance of surface limestone on the low ground below it, there can be little doubt that the boundary between the Griqua Town beds and the dolomites nearly coincides with the eastern boundary of the escarpment.

On the Kuruman River the Lower Griqua Town beds do not appear at the surface within a mile or more of the bed where it goes through the hills below Tsenin. South of the river the height of the hills decreases considerably near Gamopedi; north of the river they rise gradually and make a low rounded range, which extends to Bromley, with very few small krantzes on its eastern side; near Bromley it disappears under the sand. The Heuning Vley hills rise some 600 feet above the floor of the Vley; the kloofs on their eastern side have small krantzes and rock-shelters, but not such large ones as are found south of Kuruman in the same range.

In lithological character the beds north of Tsenin are very like those to the south, in the Asbestos-Kuruman range, described in the Annual Reports for 1905-6. The greater part of the rocks exposed on the hills is a thin-bedded ferruginous chert or jasper, often with much magnetite; it is most often brown, but red and yellow jaspers are also seen.

The top of the Lower Griqua Town beds is buried under superficial deposits just below Tsenin, but it is exposed further down the Kuruman River, about three miles above Upper Dikgathlon, where an anticline brings the Lower Griqua Town beds to the surface again for a short distance. The rocks are not well exposed, but on the right bank of the river the uppermost three feet of the glacial beds are exposed. There is room for a considerable thickness of these beds east of their outcrops before the highest westerly dipping brown and black banded jaspers are seen; they are on the western limb of the anticline; on the

[1] Ann. Rep. Geol. Comm. for 1905, pp. 166, 168.
Ann. Rep. Geol. Comm. for 1906, pp. 35-36.

eastern limb they are hidden. The rocks are dark coloured siliceous beds without lamination, and they contain pebbles of black or grey chert scattered through the matrix at rather wide intervals. Two scratched pebbles were found. These beds are very like the glacial beds at Punt in Griqualand West. Beyond the proof they give of the occurrence of this horizon and the glaciated pebbles on the Kuruman River, the most interesting point in connection with these outcrops is that they are immediately overlain by the lavas of the Middle Griqua Town or Ongeluk group. There are thus apparently no representatives of the 12 to 30 feet of laminated hard shales at the top of the Lower Griqua Town beds, such as are seen at Juanana, Punt, Monjana Mabedi, and other places further south.

The glacial beds occur again in the Madebing laagte, about nine miles above its junction with the Mashowing. Owing to my having been obliged to travel through this neighbourhood by night, I could not examine the occurrence properly, but outcrops of the glacial beds were found on the slope of the laagte near the drift by which the Madebing-Heuning Vley road crosses the laagte. On the Mashowing this horizon is not exposed, nor was it seen anywhere along the western foot of the Heuning Vley hills.

The Black Rock.

About seven miles from Upper Dikgathlon on the road to Korannaberg there is a remarkable black kopje projecting from the sand to a height of some 80 feet. From the top of the hill, which is a very well-known landmark, one can see the Korannaberg and the Kuruman hills, but it is separated from the nearest outcrops to the south, on the Kathu beacon hill, by 40 miles of sandy ground, and there are no outcrops directly north of it within the limits of the Colony. The hill is called the Black Rock, it is about 400 yards long and 150 wide. It is chiefly made of hard black, red, and brown jaspers, containing much magnetite, and some softer layers contain manganese. The eastern part of the hill is made of rather massive black beds, with a few bands of bright red rock; the western part is of thinner-bedded brown and black rock. The dip of the beds is towards W. 15° S., at about 25°, but the beds are often crumpled on a small scale.

Beyond saying that the lithological characters of the rocks would perhaps place them in the Lower Griqua Town beds, there is nothing definite to decide the horizon to which they belong. They may, however, belong to the Upper Griqua Town beds. The rocks for many miles on all sides of the hill are hidden, so that until further information is got from wells, it is useless speculating as to the evidence afforded by these outcrops on the northern course of the Maremane anticline and the Paling fault.

(b) *The Middle Griqua Town or Ongeluk Beds.*

These beds were seen in two localities only, on the Kuruman River below Tsenin and near Madebing, but there is no doubt that they occupy a wide area immediately west of the Kuruman-Heuning Vley hills, where they are covered by sand. There is an uncertainty as to the structure here, but it seems likely that the anticlinal fold that brings in the Lower Griqua Town beds at Kathu Forest, *i.e.*, the Maremane anticline, dies out not far from Kathu, and that the Middle group underlies most of the sand between the Kuruman hills and the Black Rock on the Dikgathlon-Korannaberg road.

The lavas of the Ongeluk group are first met with about two miles down the Kuruman River, below the confluence of the Matlowing. A very small distance is available here for the Lower Griqua Town group, but as there are no outcrops within a mile or so of the river, it is quite uncertain whether there is a fault with downthrow to the east in this neighbourhood, or whether the dip of the Lower beds becomes steeper than usual here. One of those suppositions seems necessary to account for the narrowness of the belt available for the latter beds.

The lowest lavas seen are green amygdaloidal rocks with numerous amygdales of quartz, chalcedony, calcite, and pyrites. A thin section (1733) shows a devitrified glass matrix, now represented by a mixture of, probably, quartz, chlorite, calcite and a little epidote, and crowded with radiating bunches of very narrow felspars and scattered elongated thin ill-defined prisms and grains of augite, together with very small crystals of magnetite. The felspars belong to the oligoclase-andesine series and are fresh.

Another mass of lava near the last has rather different characters. A thin section (1735) shows that it was originally a glassy rock, but the glass is now represented by a mixture of minerals, including some epidote and much semi-opaque whitish matter; it is crowded with very small fresh felspars, giving symmetrical extinctions about the twin planes up to 8°; augite is not plentiful, but it occurs in grains between the felspars. There is a fair amount of quartz in the matrix. The amygdales are of quartz and chalcedony with opaque whitish aggregates and some radiating bundles of extremely fine needles, which do not affect polarized light, and to which red dusty particles are attached.

The next rock seen is either a more compact lava or an intrusion. A thin section (1734) shows that the rock has been considerably altered; it consists of rather large and irregularly shaped sub-ophitic augite, crowded with dusty inclusions, and rarely showing traces of a crystal face. The felspar is in large and small, often ill-developed crystals, usually altered to epidote, chlorite, and an aggregate of colourless minerals; it is not often twinned, but the inside part, preserving the shape of a crystal, is

frequently sharply distinguished from a fresh outer zone by its more advanced alteration. There is some quartz in small patches in the matrix, which also contains very much epidote and chlorite.

There is a fairly continuous succession of outcrops for some four miles along the river near Gasese. Much of the lava seems to be like that described above, but there are other varieties. A dark green rock with small black specks in it resembles some of the lavas seen in all the Ongeluk areas further south. Under the microscope (slice 1736) it is seen to have a matrix of a felted mass of microlites or very slightly-developed long crystals of

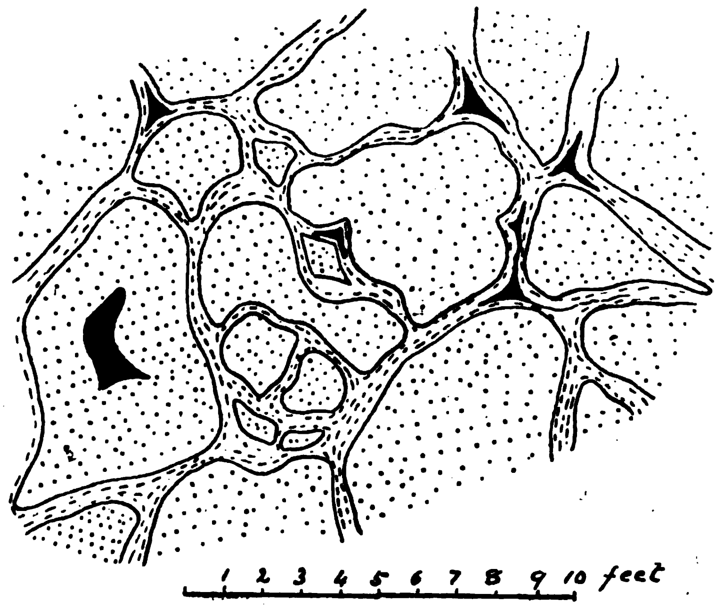

FIG. 6.—Plan of a surface of lava between Gasese and Upper Dikgathlon. The dotted areas within continuous lines represent unmodified lava; the areas marked with broken lines represent the dark rock made of chalcedony, chlorite, etc.; and the black areas are white quartz.

felspar, and probably also augite. The felspars are largely replaced by colourless aggregates, which are partly made of chalcedony. There is much opaque dusty matter, but no definite iron ore. In this matrix there are many small porphyritic pseudomorphs of a colourless fibrous mineral, probably after a rhombic pyroxene.

Some layers of lava present a peculiar structure. They are made of more or less rounded but irregularly-shaped blocks of lava, green in colour, separated by a darker and rather serpentinous-looking material, with a laminate structure parallel with the nearest surface of a lava block. (See figs. 6 and 7.) In

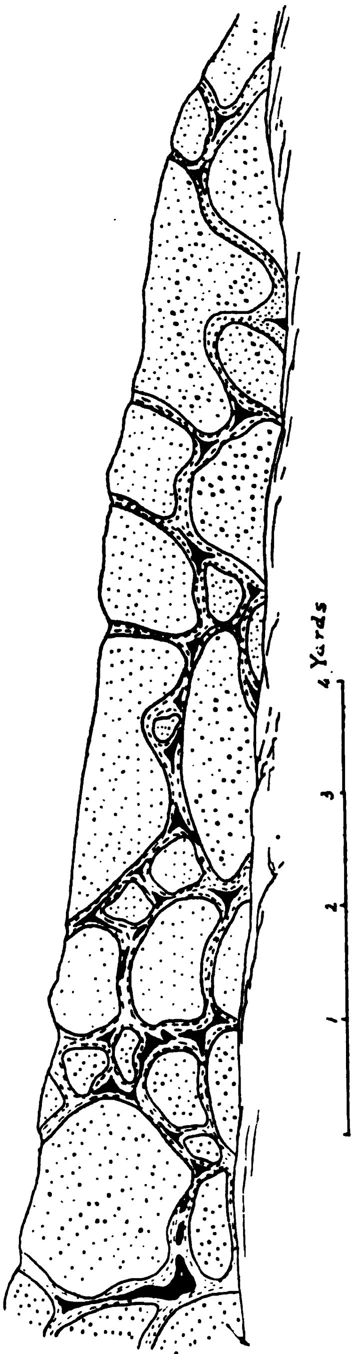

FIG. 7.—View of a vertical section through a lava flow exposed on the Mashowing below the large water-hole at Madebing. Dotted areas are lava blocks; the broken lines represent the darker rock, supposed to be mainly the products of decomposition of the lava; the black areas, quartz.

the larger interstices between the blocks there is frequently a mass of white vein-quartz, which may send thin veins along the nearest bands of dark rock, and may thus be connected with neighbouring quartz masses in other interstices; occasionally a mass of quartz is seen within a solid lava block. A plan of a horizontal section through this type of lava is seen in fig. 6, and the appearance of a vertical section through such a layer is shown in fig. 7, drawn from a lava bed in the Mashowing at Madebing. A thin section (1737) from one of the lava blocks shown in fig. 6 is seen under the microscope to be made of a matrix of felted bunches of radiating microlites and ill-defined grains, together with some recognisable felspar crystals, partly altered to a colourless aggregate; enclosed in this matrix are pseudomorphs of small quartz mosaic and chlorite, perhaps after a pyroxene. This is the only section cut from the blocks, and it indicates considerable alteration of the lava. The rock is not vesicular. A section (1738) from the darker laminated material between the blocks shows no sign of the structure seen in the lava; it consists of chlorite, chalcedony, epidote, an almost

isotropic, very pale green substance in aggregate form, filling veins and interstices, and spherical and laminated aggregates of an almost opaque pale brown substance. This dark rock may perhaps be fragmental lava, *i.e.*, tuff, altered in place; it at least appears to be due to the collection of decomposition products between blocks of less altered lava, ordinary white vein quartz filling up the spaces left after the deposition of all the dark alteration products.

The lava bands affected by this peculiar structure vary from 3 to about 10 feet (on the Mashowing) in thickness. In small outcrops the rock looks like an agglomerate, but in the large exposures it is obvious that the formation of the apparently agglomeratic structure took place during the outpouring of the lava, and that it is due to the separation of the lava into large and small blocks, fitting more or less closely, but kept apart by the deposition of the dark material or its forerunner. The dark material is very like the matrix of a true breccia found near Dikgathlon, and described below.

These peculiar lavas of the Kuruman and Mashowing Rivers undoubtedly present structures having some resemblance to those in the "pillow" lavas or "spheroidal" basalts of other countries,[1] but a noteworthy difference from the foreign rocks of which descriptions are available is that the latter are in each case amygdaloidal, while the Bechuanaland pillow-lava does not contain amygdales in the outcrops examined. The only cases in which there were original cavities in the lava blocks are the few masses with large patches of vein quartz within them, one of which lies within the area shown in fig. 6. Another point of difference from several of the foreign occurrences is that in our rocks the little altered lava blocks are separated on all sides, so far as they are visible, from the neighbouring blocks. The photograph on Plate II. of the *Silurian Rocks of Scotland*, Vol. I., represents a rock very like some of the Kuruman River outcrops, but the interstices in the Downan rock (illustrated in the plate mentioned) are filled with limestone. It has been remarked that cherts, some of which have been proved to contain Radiolaria, often accompany lavas with the pillow-structure; in Bechuanaland red banded jaspers do occur in the neighbourhood of the peculiar lavas, but they were not found *in situ*. In Griqualand West outcrops of the red jaspers were found amongst lavas of the Ongeluk series, but the pillow-structure was not noticed

[1] Ransome, *Eruptive Rocks of Point Bonita*, Bull. Dept. Geol. Univ. of California, 1893, vol. I., pp. 75-85. Amygdaloidal basalt. Cole and Gregory, *On the Variolitic Rocks of Mount Genèvre*, Q. J. G. S., vol. XLVI., 1890, p. 295. The structure is in a variolitic vesicular diabase. *The Silurian Rocks of Britain*, vol. I., 1899, Mem. Geol. Surv. of the United Kingdom, amygdaloidal lavas of Arenig age. *Ancient Volcanoes of Great Britain*, by Sir A. Geikie, contains descriptions of vesicular pillow-lavas from Scotland and Wales; vol. I., pp. 25, 193. Mem. Geol. Surv. of England and Wales, explanation of Sheet, 348, 1907. Amygdaloidal pillow-lavas of Devonian age.

near them. It is quite possible that the structure is developed in Griqualand West, and that it escaped detection.

The bright red jasper found in the Ongeluk group elsewhere[1] occurs below Gasese, though only fragments were seen. A thin section (1848) from a red and white banded jasper found below Gasese shows that it is made chiefly of chert with very minute clusters of red specks; sometimes the latter are collected together in spherical lumps. In parts of the rock there are irregularly-shaped grains of calcite or dolomite, and in the same parts there are very small short yellowish needles, slightly pleochroic and with straight extinction.

The Gasese outcrops are separated from those near Dikgathlon by a stretch of sand and limestone; the first met with belong to the Lower Griqua Town group, which here appears in an anticline with dips up to 15°. Immediately upon the glacial beds there rests a lava flow. A thin section from this rock (1740), which is dark green in colour and very hard, shows that it has been considerably altered, mainly by the coming in of much chalcedonic silica. There are numerous small porphyritic pseudomorphs of chalcedony and chlorite after some mineral, but the outlines are not well enough defined to allow the original mineral to be named; the ground mass is greenish owing to the amount of chlorite in it, and it contains many small but sharply-defined pseudomorphs after felspar; the chief replacing constituent both in the felspar form and in the rest of the matrix is chalcedony.

About two miles above Dikgathlon there is an agglomerate seen lying on a lava flow; the agglomerate consists of small and large blocks, angular and sub-angular in shape, embedded in a dark matrix. The fragments are of the spotted type, in which the spots are probably pseudomorphs after enstatite as in slice (1736) described above, but no section from the blocks has been cut. The matrix or alteration minerals alone are seen in slice (1741); it consists of chalcedony, epidote, and chlorite; but some small angular pieces of epidote-quartz-rock may represent lava fragments.

The outcrops cease about 1½ miles above Dikgathlon, and no rock other than surface deposits and gravel was heard of or met with either at the surface or in wells along the Kuruman River between Upper Dikgathlon and Matlapanin, a distance of over 100 miles along the course taken by the river bed.

Near Madebing the Ongeluk beds are frequently exposed in the Mashowing and Kgogole laagtes. Approaching Madebing from the west, the outcrops are first seen about a mile from the junction of the Kgogole and Mashowing; on the former river they occur at intervals for some nine miles up the valley, where they are underlain by the Lower Griqua Town beds; on the

Ann. Rep. Geol. Comm. for 1905, p. 182.

1 Ann. Rep. Geol. Com. for 1906, p. 44.

Mashowing outcrops cease about five miles above the junction of the Kgogole, and there seem to be no further exposures until the Campbell Rand beds above Piet Quane, some 20 miles distant, are reached. I did not, however, see the whole length of this interval, only the eight miles above the junction and five below Piet Quane.

The lavas in this neighbourhood are fine-grained green and blue rocks, in part amygdaloidal, and some of them have the small dark pseudomorphs after enstatite so often noticed further south. The peculiar structure due to the separation of the lava into blocks and the formation of a darker substance and quartz veins in the interstices, as described on a previous page, is well seen in the Mashowing section.

The Upper Griqua Town beds were not determined in the area examined. If present, they are hidden under the sand east of the Korannaberg. As previously stated, the beds of the Black Rock may belong to this group.

The Matsap Series.

This group of rocks which forms the Langeberg range in Griqualand West also builds up the Korannabergen, several isolated short ranges and kopjes in the south-eastern part of the Kalahari, and probably also the longer ranges in the same region called the Kareeboom hills, and the Onder Plaats and Groot Drink hills. Some of these hills were not visited. Several of them are isolated, and are made of rocks differing to some extent from the usual rocks of the Langeberg and Korannaberg, so that their position in the series of formations is rather doubtful.

(1) The Western Foothills of the Langebergen.

The chief of the western foothills is the Sagoup range, which rises to a height of 4,981 feet[1] and has a total length of about 25 miles. The rocks are gritty coarse quartzites and finer-grained bluish quartzites. The dips are westwards, or W. 15° S., generally, but on the south-west corner of Rooiwal there is a gentle syncline; the angle of dip rarely rises above 20°. A few miles north of the Sagoup range there are low hills on the same line of strike between Malby and the Inchwanin water hole; one of these hills is an anticline.

Slates or sericitic quartz-schists were not seen in those parts of the Sagoup range visited, but sericitic slates occur in a dry well on the northern part of Omvrede, in the valley between the

[1] The heights given in definite figures in the text and on the maps are taken from the Annual Reports of the Surveyor-General for 1901 and later years.

Sagoup range and the Langeberg. These slates have a moderately high westerly dip, and can be placed in the Matsap series without hesitation. There are low outcrops of typical Matsap quartzites in their neighbourhood.

It is uncertain to which part of the Matsap series the Sagoup rocks belong. The volcanic rocks which are characteristic of the Middle Matsap beds east of the Langeberg have not yet been found in place west of the main range nor in Korannaberg, and the lithological characters of the Lower and Upper beds are not sufficiently distinctive and persistent to allow one to carry out at present the threefold division[1] of the series throughout the area occupied by it.

On Malby and Gringley there is a low ridge of westward-dipping Matsap beds, striking about N. 5° W.; a break of three miles separates this ridge from the extreme southern end of the Korannabergen. At the south end of Gringley a well has been sunk on greenish-grey sericitic phyllites; these rocks are overlain and underlain by quartzites with schistose bands in them. The schistose bands are evidently altered sandy rocks, with enough clayey matter in them to give rise to sericite.

(2) The Korannbergen.

The Korannabergen are a long scattered group of hills, which rise steeply out of the sand to various heights up to about 1,100 feet above the surrounding country. The highest point in them seems to be the top of the hill immediately north of the water at Blaauw Krantz. In general appearance they are just like the main range of the Langebergen, and they are largely made of the same kind of rock. In the higher parts of the hills the tops are remarkably flat; the beds are cut off by a plane at various heights from 700 to 1,000 feet, or over, above the sandy ground; but in the lower hills the different powers of resistance to the weather possessed by successive bands of rock have had effect in making steep ridges and valleys parallel to the strike.

The westernmost range is the longest, and it is broken only by two transverse kloofs south of Dedebin. Some six miles north of Dedebin (where the Police Camp was in 1907) the range drops below the level of the sand, but four low ridges further north mark its continuation. The last outcrop is about 17 miles north of Dedebin, and the Matsap beds were not seen again on the same line of strike; no outcrops were met with on the Kuruman River in this position.

The western range is made of coarse and fine quartzites; occasional layers of well-rounded quartz and red jasper pebbles, and isolated pebbles of the same nature, occur in them. The coarse rocks are of the reddish purple colour characteristic of many of

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[1] See Ann. Rep. Geol. Comm. for 1906, p. 50.

the Langeberg rocks, but thick bluish and almost white quartzites occur. The gritty rocks are sometimes sericitic. The general trend of the hills is a few degrees west of north, parallel to the strike of the rocks.

Near Naauw Poort the range branches, a second range trends north-north-east to Blaauw Krantz, though the dip of the beds remains nearly the same as in the westernmost hills, but the observed dips were all west or within 10° north of west, and never south of west. Thus the broken groups of hills near Blaauw Krantz and east of that place do not trend parallel with the strike of the beds, but usually some 20° eastwards of the strike. The Blaauw Krantz hills and the eastern hills are made of rocks similar to those of the western range, and the dips are generally westwards at angles up to 35°. At only one place, near Whyenbah, do the rocks make an anticline with easterly dips on the eastern side.

At two localities near Blaauw Krantz there are overturned anticlines with westerly dips, and these are made obvious by the occurrence of the Griqua Town beds in the arches of the anticlines. One of the places is at the north end of a ridge about four miles east-north-east of Blaauw Krantz. The Matsap beds dip westwards at about 45°, and at their base contain many lumps, more or less angular, of the magnetic-banded rocks of the Griqua Town beds, and the colour of the Matsap quartzites is darker than usual. The largest boulder I saw was 18 inches in length. There are also small rounded pebbles of bright red jasper.

The second locality is on the eastern side of the group of hills south of Blaauw Krantz. The dips here also are all towards the west.

The easternmost hills of the Korannabergen are low kopjes made of sheared mottled coarse quartzites, often false bedded, containing thin layers of round pebbles of quartz, quartzite, red jasper, and black slaty rocks. The beds dip west at about 30°. These eastern hills are on the strike of the main range of the Langeberg, allowing for a slight change of trend from a few degrees west of north to north or a few degrees east of north, corresponding to the change of strike in the Sagoup-western Korannaberg rocks. A gap of some 11 miles separates the southernmost hill of the eastern group from the Langebergen.

(3) *The Langeberg Main Range.*

The only part of this range visited was the western side from Glen to Mount Temple.

The northern end of the range has a synclinal structure, and on Dichaking there is a slight cross fold which makes a large mass of quartzites project considerably from the range between Dichaking and Rooiwal.

For some 13 miles along the main range from Lukin to Top Dog the beds are very much folded, and the folds are well exposed on the sides of the steep kloofs which cut into the western flank of the range. These folds are overturned, and their axes dip eastwards at about 45°; they are not quite isoclinal, the eastern limbs of the arches are less steeply inclined than the western. Their general effect is to bring the beds down towards the west (see fig. 8). The rocks on this side of the range are the usual mottled coarse purplish quartzitic sandstones with isolated pebbles, probably belonging to the upper of the three sub-divisions into which the Matsap beds in the eastern part of the Langeberg were divided. No outcrops of the volcanic beds (middle division) were met with, but some large fragments were seen on Lapane; they may have been pieces carried down from the Olifants Hoek hills.

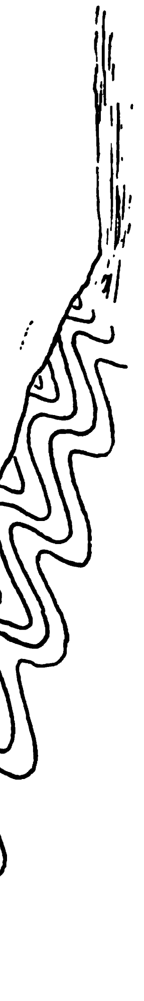

FIG. 8. Diagrammatic sketch of the overturned folds seen in a long kloof west-north-west of Lapane beacon on the Langeberg. The length of the mountain slope is about 1¼ miles.

(f) *The Isolated Hills in the East of the Southern Kalahari.*

From the Inchwanin hill on the north to the Koodoos Kop on the south there are 10 isolated hills and ridges projecting from the sand. Their approximate positions are marked on the map. Of these only Inchwanin, Makokokoie, the hill five miles east of the latter, and the Kuip range were visited, but the characteristic appearance of the others left no doubt as to their nature.

The Inchwanin hill is made of the usual purplish gritty quartzites of the Matsap series, dipping about 3° south of west at angles between 20° and 30°. It is an important place, because there are numerous small holes in it which hold water for a long time after rain. The water in the largest hole was three feet deep and about eight feet across at the time of my visit. Some of the holes are small depressions at the intersection of cross-joints with the main joint-planes (E. 10° N.); the largest hole looks as though it had been enlarged by breaking off slabs of the quartzite. They are all several feet above the level of the sand, and are approached over a slope of rock which is rather dangerous for cattle to walk on.

Another interesting feature here is the presence of numerous rock carvings of various kinds; representations of the giraffe, several kinds of antelope, lion, baboon, tortoise, men with bows and arrows, and various circles in concentric patterns, spirals, twisted lines, and small conical hollows two inches wide and one

deep. They are incised on smooth surfaces, which are covered with a thin brown hard film. Many of the lines are so shallow that they are scarcely perceptible on passing the finger over them. Others are much more deeply hollowed, evidently by repeated blows from a blunt instrument. The brown film has not been formed over the incised lines.[1]

For some 6 or 10 feet above the level of the sand the rocks at the south-western corner of the Inchwanin hills are very smooth, and in parts quite polished. They have a gently curved or flat surface, very like the front slope of *roches moutonnées*. Surfaces of this sort are frequently seen on low outcrops in the Kalahari, but they extend further up the side of the hill at Inchwanin than elsewhere. At first I thought the surface might be glaciated rocks recently stripped of Dwyka tillite, but they are not striated, and no tillite or boulders such as commonly occur in that rock were found in the neighbourhood. At other places along the hills the smooth polished surface is much smaller or altogether absent. There can be no doubt that the polishing has been accomplished by sand blown across the rocks within a few feet of the ground. The fact that such polished surfaces are restricted to within a very few feet of the surface of the sand and are never seen higher up confirms the general impression as to the movement of sand in the Southern Kalahari conveyed by the nature of the dunes, that at present the movement is slight, and has been so for many years past.

The Kuip range is made of the usual gritty quartzites, which dip towards W. 10° S., but at the south end the dip turns towards S.S.W., and there is a slightly projecting shoulder at the south-eastern extremity.

(5) *The Inkruip and Scheurberg Ranges.*

The Inkruip range is made of gritty purplish quartzites, with sericite commonly developed; the beds generally dip S. 20° W., but on the eastern side there is an anticline. A rough cleavage has been produced which tends to obscure the bedding planes, and which is more important in determining the action of the weather than the bed planes. The range is separated by two miles of sand from the smaller Kakoup ridge to the north-west, but the Kakoup rocks almost certainly belong to the same formation as the Inkruip beds. The quartzites there probably belong to the Matsap series, though I did not find the red jasper pebbles in them.

The western range on Scheurberg was not visited. It is on the strike of the Inkruip beds, and presents a very similar appearance. They are both different in appearance from the

[1] Some tracings and photographs of these drawings were made and are in the South African Museum.

sharply serrated ridge, Scheurberg proper, on which the Trig. beacon stands, and which is made entirely of Kheis beds.

Circumstances prevented me from going to the southern end of the western Scheurberg ridge, where there must be an interesting junction with the Kheis beds of the hills trending N. 40° E. from Rooi Zand. The junction probably lies in the neighbourhood of the poort through which one of the roads from the Langebergen to Upington passes.

On looking at the map it will be seen that the places where the Kheis beds occur in the south-east of the sand-veld lie directly between the Langeberg-Korannaberg ranges and the western Scheurberg and Inkruip ridges or a line drawn through them and produced north-north-westwards. It is likely that the Kheis beds mark the position of a large anticline in the Matsap series.

(6) The Outcrops at Kuis on the Molopo.

About 86 miles north of the Kakoup outcrops of the Matsap beds the Molopo has cut through a belt of purple quartzites with red jasper fragments, which can without hesitation be referred to the Matsap series. The section was examined between Kolingkwane and Kuis, a distance of 12 miles, but I was informed that similar rocks crop out again 16 miles below Kuis on the Molopo.

In this part of the Molopo the valley is a steep-sided trough, about 150 feet deep and from 200 to 500 yards wide. There is no definite river bed; at places, especially at Kolingkwane, Mogogobe, and a short distance above Kuis, the Matsap beds crop out in many spots on the floor of the valley, sometimes forming a bar which extends almost across the valley. Generally the quartzites appear in steep cliffs, which at Kuis are vertical, for nearly or quite 100 feet above the floor of the valley. For considerable distances there are no quartzite outcrops, but here the sides are made of Dwyka tillite filling ancient valleys in the quartzites.

The rocks are grey, blue, and purple quartzites, often false bedded, dipping at high angles towards W. 20° S., or slightly nearer west.

There are no outcrops in the sandy country between those rocks and the Kuruman River, and from information got from various people during the journey, it seems very unlikely that there are any outcrops between this part of the Kuruman River and the Kuie and Kakoup rocks.

(7) The Onder Plaats-Groot Drink Ridges and the Hills North-East of them.

Though many of the quartzitic rocks described in this section of the Report are isolated, and therefore cannot be traced in continuity with the strata in Korannaberg or Langeberg, their litho-

logical characters enable one to place them in the Matsap series without much hesitation. Those now to be mentioned present some differences from the typical Matsap beds, and their position in the geological succession is at present more doubtful, though it will be seen that the reasons for placing them in the Matsap series are more weighty than those which would assign to them a lower or higher position. It is more convenient to call them Matsap beds than to make a new group of them.

On Groot Drink there are three ridges of quartzites and quartz phyllites, with thin conglomerates near the base, striking about N. 15°-20° W. (See fig. 3.) At the southern end the westernmost ridge is terminated abruptly on Sterkstroom by the Groot Drink-Sterkstroom fault, which has a N. 25° E. course. The two eastern ridges rise from the sand. The beds in the two western ridges dip eastwards, those in the easternmost ridge dip westwards, so there is a syncline here. The junction with the Wilgenhout Drift beds is seen on Sterkstroom, but further north it is concealed by superficial deposits. The lowest beds are sericitic quartzites, but a few feet up there are conglomerates with a quartzite matrix and pebbles of quartzite, quartz-schist, and quartz. The quartz-schist pebbles evidently come from the Kheis beds, but I found no pebbles of the green cleaved lavas or slates of the Wilgenhout Drift beds. Then follows a thick group of massive quartzites and quartzitic grits, more like the Matsap beds than any other rocks in this part of the Colony; they are distinctly bedded, and some of them are false-bedded. This westernmost range is continued north-north-west for about eight miles across Groot Drink, Onder Plaats, Zonder Huis to Zwart Kop, where it ends in sand. On Onder Plaats it consists of thin quartzites, with bands of thinly laminated micaceous phyllites, which are more micaceous than any of the phyllites seen in the eastern foothills of the Langebergen or elsewhere in the Matsap series, but the bedding planes throughout these hills are much more distinct and have greater result in determining the lines of greater weathering effect than the bed planes in the Kheis series. The two eastern ranges have similar characters.

The Karreeboom Vlakte range projects from the sand five or six miles north-east from the easternmost range of the three just mentioned. I did not visit it, but Mr. Lanham brought me specimens from it where the desert road passes through it north of the Karreeboom Trigonometrical beacon; these rocks are quartzitic grits of the Matsap type, like the coarser quartzites of Groot Drink and Onder Plaats. The trend of the Karreeboom Vlakte hills is about N. 20° W., as observed from a few miles south of them on Zwem Kuil, but north of the Karreeboom Trig. beacon it turns more to the north, and the Kamkuip beacon is placed on the continuation of the range.

The total thickness of the beds seen in the easterly dipping series on Groot Drink must be over 2,000 feet. They are certainly younger than the Kheis beds, fragments of which they

contain, and their position with regard to the Wilgenhout Drift beds shows that they are younger than the latter. There is no reason to place them in the Transvaal system, to no member of which have they any marked lithological resemblance. They resemble the Matsap beds in that they are chiefly coarse quartzites, but they do not appear to have fragments of red or brown jasper in them, and the less siliceous portions contain more sericite than is seen in the shaly beds in the Matsap groups of the Langebergen, etc. Their sericitic character can of course be explained by the fact that they have suffered considerable pressure and folding, as evidenced by their high dips, though the observed sections through the hills are not extensive enough to show repeated close folds, if present, like those exposed on the western flank of Langeberg.

The chief difficulty in accepting these rocks as of Matsap age is that the Koras series not far to the west are not cleaved or closely folded, and the Koras series is supposed to represent the Pniel group in this area. It is true, of course, that the latter correlation may be wrong. It is also possible that the down faulted block of the Koras group, assuming its greater age, was never subjected to the pressure that deformed the Onder Plaats rocks.

THE KARROO SYSTEM.

Rocks belonging to this system were seen between the north corner of Upington Common and the neighbourhood of the German border north-west of Rietfontein, a distance of about 126 miles in a straight line running north-west, and between the German border on Obobogorop and Kolingkwane, 130 miles or so in a north-easterly direction. As pointed out in the Introduction, there is reason to think that a very large part of this great area is underlain by a thin layer of rocks belonging to the Karroo formation, though the rocks are very rarely seen.

By far the greater number of the exposures belong to the Dwyka series, but sandstones and shales that can be placed in the Ecca also occur.

The distribution and thinness of the Karroo deposits suggest that the present form of the ground in Gordonia is now not very different from what it was at the time of the deposition of the Dwyka series.

The Dwyka Series and Overlying Shales.

The Dwyka series in Gordonia consists of boulder beds, in some places laminated and in others without lamination. These rocks, which may conveniently be called "tillites,"[1] are not often

[1] The term "tillite" was invented by Prof. Albrecht Penck whilst on a tour through South Africa in 1905; it is used for rocks which look like the well-known till or boulder-clay and allied rocks of Europe and America, but have a hard stony matrix. Its use does away with the necessity of such expressions as "hardened boulder-clay."

exposed, but their presence under the soil is indicated by the numerous boulders and pebbles of rocks foreign to the immediate neighbourhood left behind after their matrix has disappeared.

The first indication of the Dywka was seen in the north-western corner of Upington Common, where the Upington granite passes under a sandy soil, in which lie boulders of granite, quartzites, grits, blue diabases—some of them amygdaloidal—dolomite and chert. Some striated boulders were found here. On Areachap there is a well on the edge of a pan close to the roadside. The bottom of the well is in gneissose granite, which is overlain by some 50 feet of tillite, reddish in colour, containing boulders and pebbles of granite, gneiss, amygdaloidal diabase, banded black and red magnetic jasper like that in the Griqua Town beds, red jasper, quartzites, and a very hard quartzitic conglomerate. The uppermost 8 feet of the well section are shale with boulders, and there are two six-inch layers of clayey limestone.

Similar tillite with reddish matrix is seen in a well on Grond Neus. From this well were obtained some boulders of a peculiar igneous rock, not previously noticed either in the Dwyka or *in situ*; the rock consists of a dull white matrix with small dark crystals in it. Under the microscope (1815) the matrix is seen to consist of a confused mass of aggregated minerals, saussurite, like the decomposition product of some felspars, a little quartz, brown mica, and magnetite. The crystals are pseudomorphs of a green fibrous serpentinous mineral, with calcite filling wide cracks parallel to the green fibres, and some magnetite; their shape is like that of a pyroxene.

These wells were the only places where the matrix of the tillite was seen in this part of Gordonia, and further north the matrix is always grey or blue, as it is in almost all the other recorded outcrops of Dywka tillite in Cape Colony. The specimens brought to Cape Town by Dr. Nobbs from Norokei and Eenzamheid, 28 and 40 miles north-west of the Upington northern corner beacon, are greyish blue rocks.

In the immediate neighbourhood of Bloemfontein House the shales and thin sandstones of the Zwart Modder beds crop out, but towards the west and north the Dwyka covers these beds. Three miles west of the house there is a patch of thin shales with lenticles of clayey limestone, evidently belonging to the Karroo formation, and possibly resting directly upon the Zwart Modder beds without the intervention of tillite. The latter occurs round the shale area, and is of the usual grey colour, with boulders and pebbles of various rocks similar to those noted above from Areachap.

On Abiam there is a well sunk 30 feet through greenish grey tillite, containing many scratched boulders. There are many quartz-porphyry boulders here.

Between the north side of Bloemfontein and the neighbourhood of Rietfontein the surface is either loose red sand, or hard,

with immense numbers of pebbles and boulders scattered over it. These patches of hard ground are sparsely covered with small bush. The boulders and pebbles are of various rocks, and undoubtedly come from the Dwyka tillite. **Striated boulders are quite as numerous here as on the tillite** plains of Prieska or the Western Karroo in Calvinia and Ceres; there is indeed a close resemblance to these distant areas.

Near the south-eastern boundary of Wit Kop the main road passes near a low hill, with a beacon on it, conspicuous on account of the flatness of the surrounding ground, made of unusually hard blue tillite. There are many lenticles of compact blue limestone in the tillite of this neighbourhood, but the hard rock referred to above is not calcareous. A thin section of this rock (1820) shows characters that have been developed long subsequently to the deposition of the tillite, and are very probably due to the proximity of a dolerite intrusion not yet exposed at this spot. Near Wit Kop dam a well penetrates 25 feet of hard blue tillite, and then enters dolerite of the usual Karroo type. The beacon-hill rock consists of angular and rounded grains of quartz and felspar, chiefly the former, quartzite, and a felspathic igneous rock that may have come from the Pniel lavas, set in a fine-grained matrix of various minerals, amongst which quartz and biotite have alone been recognised. The mica is the red-brown strongly pleochroic sort found in the slaty rocks of the Malmesbury beds near their junction with granite; it is very abundant in minute flakes, and has undoubtedly been developed *in situ*. Another new mineral is also very abundant; it is colourless, with fairly high refraction and weak double refraction (about that of quartz); it forms very minute grains and elongated grains, with occasional straight edges, parallel to which the mineral extinguishes; it has not been identified. Some metallic grains are probably magnetite; they are frequent, but usually very small.

Between the well and the dam at Wit Kop there is much hard calcareous tillite of a pale grey colour, often stained yellow or brown by oxides of iron. A thin section of this rock (1824) shows chips and grains of quartz, felspar, quartz, grit, quartzite, chert, micropegmatite, and cherty limestone or dolomite, in a matrix containing much calcite.

Amongst the numerous boulders, some of them striated, lying on the surface on Wit Kop, and evidently weathered out from the tillite in place, the following were noted: Granites and gneiss, many with white felspars porphyritically developed, and generally with biotite, more rarely muscovite; fine-grained rocks of similar composition; the porphyritic type is not known amongst the Upington granites. There is also a red felspar rock, with a matrix of red micropegmatite visible under a lens. Amygdaloidal and compact blue-green diabase, such as might come from Pniel lavas and dykes of pre-Karroo age; one of these types of rock is remarkable, in that it contains green epidotic pseudo-

morphs after felspars up to $1\frac{1}{2}$ inches long. There are quartzites and sandstones of various kinds; some are bluish or white, others reddish, like many beds in the Zwart Modder series; grits; felspathic grits like the felspathic rocks at the base of the Black Reef beds in Bechuanaland. There are conglomerates with quartz and chert pebbles, like the Black Reef conglomerates, and another conglomerate with dark quartzitic matrix and large pebbles of chert and banded jaspers, some of which are red. (This conglomerate occurs in large boulders, often several of them lie near each other; they have caused some prospecting, their presence being supposed to indicate a conglomerate or "banket" reef underground; they have, however, certainly travelled far from their parent beds, the position of which is unknown, but probably lies north of Gordonia.) There is much dolomite and chert, and red and black banded magnetic jaspers, but no yellow and black jaspers like the brown rocks in the Griqua Town series of the Kuruman hills, etc. This collection of boulders is not very different from that which one finds in the Dwyka tillite along the south of the Karroo, but granites are less abundant in the north and the brown Griqua Town jaspers apparently absent, as well as typical Matsap purple quartzites. The red micropegmatitic rock and the dark conglomerate seem to be peculiar to the Gordonia tillite.

On Springbok Vley some of the flat ground is directly underlain by the tillite, and boulders of a coarse porphyritic granite two feet long have weathered out from it. There are also numerous calcareous layers and spherical concretions. The highest part of the tillite here is a rock poor in pebbles, and above it lies a sheet of intrusive dolerite, forming the slopes of the low hill on which Springbok Vley Trigonometrical beacon is placed. Above the dolerite are some thin patches of hardened sandstones and shales, only 3 or 4 feet thick, without pebbles.

On Obobogorop there are wells sunk 70 feet in grey shale and mudstone with few boulders, though the surrounding ground is covered with the usual assortment of boulders and pebbles. No black shales are exposed. The tillite is exposed again near the north-west corner of Lang Vley, where it is again capped by dolerite.

On the west side of the pan on Onderste Narougas there is a plain of hard ground with boulders; a water cutting reveals grey shales with few boulders, and thin lenticular limestone beds.

On Uitzak the usual boulders occur on flat ground near the northern boundary, but the boulder beds are overlain by 150 feet of thin dark grey shales, containing plant fragments, amongst which *Glossopteris* was found. These shales form a krantz capped by dolerite. These shales were followed at short intervals round the western side of Kopjes Kraal pan across Oxford to Schepkolk; on the two latter farms they contain striated boulders, but these decrease in number upwards as the rock is followed into the dolerite-capped hills called the Eierdop

range. A calcareous sandstone bed in the Dwyka series on Schepkolk (1832) is made of grains of quartz, felspars, some muscovite and bleached biotite, and zircon, set in a matrix of calcite, which is a mass of rather large interlocking crystalline areas.

Shales with boulders are exposed in a pit on Schepkolk, near the western side of Haakschein Vley.

On the Eierdop hills about 60 feet of shales without boulders are exposed. They contain silicified wood of the type found in the Ecca shales in several parts of the Colony. Above them is a prominent white band, due to the presence of five feet of whitish coarse arkose, a rock which has not been recorded from the Ecca or Dwyka series elsewhere. A thin section (1831) examined under the microscope shows that the rock is made of grains of quartz, orthoclase, and occasionally plagioclase, with a few pieces of garnet and brown mica. The felspar is cloudy and nearly opaque. Above this arkose there is only dolerite, to the presence of which the hills owe their existence.

On Mooi River and near Rietfontein there are layers of gravelly rock with calcareous matrix in the shales containing boulders. The gravel layers are only six inches thick at most, often thinner, and they are sometimes contorted. The pebbles in those layers are very abundant and closely packed, and they do not exceed three inches in length.

Around Rietfontein boulders weathered out from the Dwyka tillite are scattered abundantly over the ground; between the village and Sannah's Poort they are remarkably abundant, and their average size is larger than usual. Well-striated boulders can be found without difficulty. They consist of various rocks of the same kinds as those quoted above from Witkop. About a mile and a half from the German border at Sannah's Poort, down the stream-bed leading to Rietfontein, the base of the Dwyka is exposed in section. This is the only place where the junction was seen in a position where it could be closely examined; the other exposures of it were down wells. The base of the Dwyka is a grey unstratified tillite with many boulders. The rocks underlying it are thin shales dipping south-south-east and belonging to the Zwart Modder series. I could find no striated surface; the shales are broken at the junction, and are obviously unfavourable rocks for retaining glacial striae.

Some small patches of pebbly shale are exposed at the surface in the western part of the great Haakschein Vley, but in the eastern part of the pan itself only beds which resemble the Zwart Modder shales and sandstones were seen. About three miles north of the Wind Hoek dam there is a small kopje of, probably, Dwyka shale, a softer and greyer rock than the Zwart Modder shales of Blaauw Krantz, containing pebbles, amongst the sand dunes east of the Vley.

Exposures in Wells along the Kuruman River.

The well at Witdraai, about three miles up the river from its junction with the Molopo, is 80 feet deep. The upper 40 or 50 feet pass through sandy limestone of recent age, but below that level thin grey and greenish shales of fine texture, which break up rapidly under the influence of the weather, were met with. These may belong to the Karroo formation, though no delnite proof was obtained. The only other well which reaches the rock underlying the surface deposits is at Matlapanin, 70 miles by road up the river from Witdraai. I was at the well during the night, and could not find the thickness of the superficial deposits, but the well is 58 feet deep, and quantities of tillite with boulders of crystalline limestone, diabase, and gneiss, two of which were found to be typically glaciated boulders, have been thrown out from the well. Some of the material is boulder shale.

The Kuis-Kolingkwane Section.

Along the Molopo from Kuis to Kolingkwane the Dwyka tillite fills old valleys in the Matsap beds. Both formations are overlain by superficial limestones and other rocks, and are only exposed in the valley of the Molopo.

Between Kuis and Mogogobe the Dwyka forms two wide bands, separated by a narrow steep-sided ridge of Matsap quartzites. The beds were traced 80 feet up the side of the valley. The outcropping beds are brown-weathering hard grey-blue limestones and thin sandstones; they lie horizontally. Outcrops of tillite are rarely seen, and appear to be confined to the lower part of the slopes, but higher beds must contain boulders, for weathered out boulders are not only found on the lower slopes where the outcrops were seen, but also occur some 40 or 50 feet up. Several typical glaciated boulders were found at four or five places where a search was made, not only below Mogogobe, but between that place and Kolingkwane. The most abundant rock forming the boulders is cherty limestone or dolomite from the Campbell Rand series, but granites, gneisses, and amygdaloidal and compact diabases were frequent.

Between Mogogobe and Kolingkwane the tillite and overlying sandy shales and limestones occur in a similar manner.

The time at my disposal for the examination of the 12 miles of the Molopo between Kuis and Kolingkwane was very limited, and I could not make a careful search for exposures of the junction of the Dwyka beds with the Matsap quartzites; it is probable that the junction is visible somewhere between the places mentioned, though there is much debris from the superficial deposits which cap the steep slopes.

It is of course impossible to trace the boundaries of the Dwyka beyond the narrow limits of the valley, but enough is visible to

prove that the tillite and associated Karroo beds fill valleys over 100 feet deep in the Matsap quartzites; the old valleys cross the Molopo at about a right angle and were deeper than the Molopo valley now is. As the right bank of the Molopo is in the Bechuanaland Protectorate, the Karroo formation extends into that territory for an unknown distance.

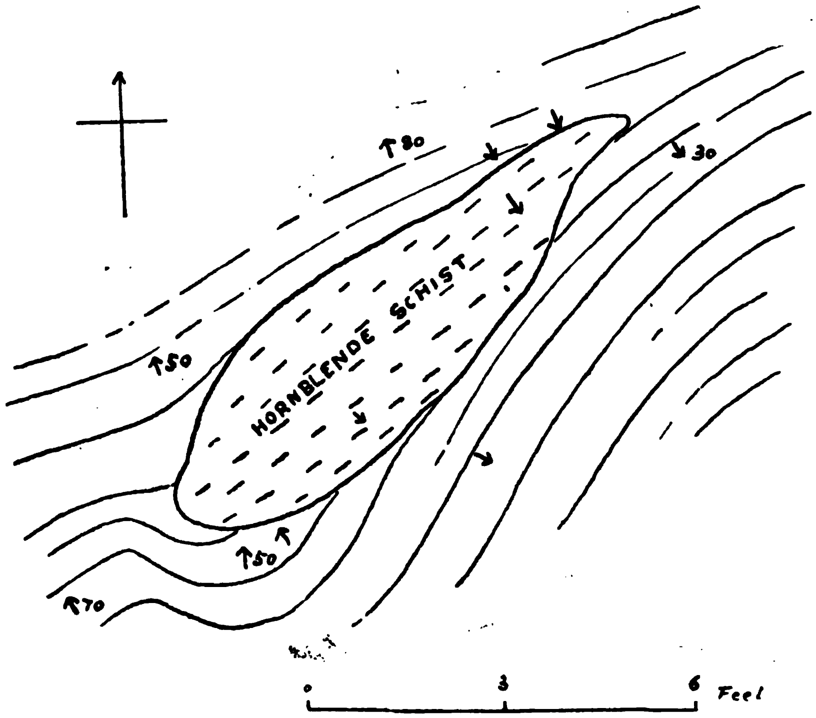

FIG. 9.—Plan of "eye" of hornblende-schist in quartz-schist on Kheis.

INTRUSIVE ROCKS OTHER THAN GRANITES.

Dykes and sheets of various igneous rocks penetrate many of the sedimentary formations from the Kheis beds to the Karroo formation in this district. They are described below in the probable order of their intrusion.

(1) Schistose Dykes in the Kheis Series.

On the farms Kheis and Tsebe there are many narrow dykes of a dark somewhat schistose rock. Usually the dyke either follows the schistose planes in the Kheis beds or forms a small angle with them; occasionally a dyke cuts across the schistose lanes at angles up to 45°. The ends of the hornblende schist

masses are rounded off, as in figs. 9 and 10. The dykes may be of any size from a few feet to more than a mile in length.

The rocks of all these dykes are very much alike and in the hand specimens remind one of hornblende-schist, but in some there is little evidence of parallel structure. Specimens from five dykes were cut for the microscope. Section (1756), from a dyke 4 miles north-east of Kheis, consists of hornblende, chlorite, zoisite, epidote, quartz, ilmenite and sphene, and calcite. No

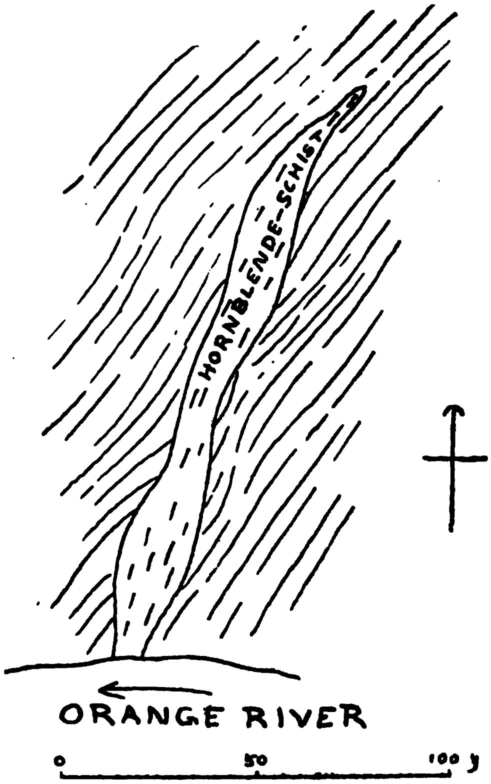

FIG. 10.—Plan of a hornblende-schist dyke in Kheis beds, Kheis.

parallel structure is discernible. The hornblende is in irregular plates and fibres; it is pleochroic (X colourless or nearly so, Y olive green, Z blue). The chlorite is in nearly rectangular lath-shaped sections. The other minerals are in small grains, and no felspar is visible. There is very little ilmenite left, but there are skeleton forms of it surrounded by aggregates of sphene and leucoxene. A rock from the 4th dyke below Kheis (1757) has more hornblende in it, otherwise it is similar to the last rock. A slice from a dyke one mile below Kheis (1758) is just like the first rock. One from 600 yards east of

Kheis Police Camp (1759) is a rather similar rock, in which the chlorite is more abundant and in larger crystals. Section (1760) from the "eye" of hornblende schist shown in fig. 9 consists of a granulitic mixture of the same variety of hornblende as in the previous rocks, quartz, epidote and perhaps zoisite, and magnetite or ilmenite and sphene, but apparently without chlorite. These hornblende-schists differ from the hornblende-schists of Garaphoane in the variety of amphibole as well as in other details, and they are not like the hornblendic rocks of Upington Common. They are probably greatly altered dolerite rocks which invaded the Kheis beds before the latter became schistose. That the hornblende schists have been greatly sheared is obvious from their appearance in the field; they have a parallel structure and the schistose planes often turn in direction in conformity with the nearest planes in the Kheis schists.

(2) Other Intrusions of Pre-Karroo Age.

A dark band lying in the quartz-schists of Uitkomst was taken in the field to be a dyke of the Kheis type, but a thin section of the rock (1805) shows it to be of quite a different nature. It has a well-developed granulitic structure, the various minerals form more or less uniformly-sized grains; they are green pleochroic hornblende of the kind that occurs in the Upington augite-hornblende-granulite, quartz and plagioclase, together with some magnetite and a little brown biotite. This rock is more nearly related to the granite intrusions of Upington than to the more basic altered dykes of Kheis.

A narrow dark band in the Kheis schists of Achterkop is made of large and small ragged plates of pale pleochroic blue-green hornblende like that of the Kheis dykes. It (1845) also contains chlorite, an epidote-zoisite mineral, and very much of a colourless aggregate of quartz and possibly felspar.

There is a quartz-diabase dyke 150 feet wide traversing the Kheis beds of the Kuie pan nearly parallel to their strike; it is slightly finer grained at the margins. Thin sections (1749 and 1750) show that it is a holocrystalline rock, chiefly made of felspars, augite, hornblende, quartz, biotite and magnetite. The augite is colourless and has partly idiomorphic forms; it has the basal striation. The hornblende occurs as continuations of the augites, they have a cleavage in common; the hornblende is a moderately pleochroic green variety, and seems to be an original constituent; it is often partly changed to chlorite. Much of the felspar is considerably decomposed with the formation of sericite, especially in the middle of the crystals, which are partly idiomorphic and are plagioclase. There is also much orthoclase forming micropegmatite with quartz in the coarser rock. The

biotite is mostly altered to chlorite. There is much magnetite and a little apatite, and calcite in rather large masses. The finer-grained rock has no micropegmatite, and the augite is in small grains.

At Masilibitsani, on the Mashowing, there is a quartz-porphyry dyke which takes an S-shaped curve across the Mashowing; it commences on the south side of the river and soon attains a thickness of 10 feet, and has a N. 15° W. course; it swells to 80 feet and bends round to E. 20° N., crosses the river and turns N. 20° W., disappearing under superficial deposits. Along the two edges in contact with the granite, the rock is much finer grained than elsewhere. The middle part consists of corroded quartz crystals lying in a matrix of interlocking quartz areas clouded by minute specks and flakes of various kinds, and green chlorite. Calcite is an abundant constituent as very small grains (1723). Two slices (1624, 1725) cut from the finer-grained edges show a flow-structure parallel to the walls of the dyke. The matrix is separated under crossed Nicols into smaller areas than in the middle part of the dyke, but is otherwise similar; there are small specks of a sericitic mineral. There are clear oval areas of quartz-mosaic, which may represent quartz crystals, but there are no uniform corroded quartz crystals as in the middle rock. This dyke is only seen traversing granite, but it is possible that it was a feeder of the acid lavas of the Zoetlief beds, an outlier of which occurs about 13 miles further up the valley.

There is a small mass of apparently intrusive rock in the inlier of the Campbell Rand and Lower Griqua Town beds in the denuded anticline of Matsap beds east of Blaauw Krantz. It is a very much altered rock (1847), consisting of epidote, chlorite, quartz, possibly some felspar along with the quartz, and much magnetite and ilmenite with granules of sphene. Its original structure is obliterated.

In the Lower Griqua Town beds, near Lower Dikgathlon, there is a dyke of almost black rock about 100 feet wide with a northerly course. A thin section of this (1739) shows it to be an altered rock with scarcely any original structure preserved; it consists almost entirely of quartz and chlorite. There is some clear quartz, apparently original, and round these patches, which look as though they filled spaces between felspars or other constituents, new quartz has grown, crowded with small specks of a chloritic mineral, which also occurs alone in irregular patches.

Through the granite of the Detseping Reserve, opposite Keang on the Mashowing, there is a long diabase dyke about 200 feet wide. It consists (1721) of large chlorite pseudomorphs after an apparently rhombic mineral, probably enstatite,

embedded in a mass of alteration products, chlorite, epidote, and tremolite, together with fairly large and fresh augites, which are in process of conversion into pale uralitic hornblende; there are also patches of leucoxene.

The three intrusions of diabasic rock near the Orange River on Groot Drink, Leeuw Draai and Koras have some features in common, and may perhaps belong to one period of igneous activity. They do not closely resemble any other intrusive rocks in this area, and perhaps they are more like the fresher lavas of the Koras series than any other igneous rock in the north of the Colony. They all occur along lines of faulting, and have a strong general similarity in appearance.

The Groot Drink rock forms an oval outcrop exposed over a length of about three miles in a north-north-east direction; it lies between the greater part of the Wilgenhout Drift beds north of the river and the Sterkstroom fault, but the contacts are not exposed. A thin section (1774) shows it to be a fairly fresh glassy ophitic doleritic rock. The augite is quite fresh and is in irregularly-shaped, rather large colourless ophitic masses enclosing felspar and pseudomorphs of a greenish, slightly pleochroic mineral agreeing with bastite; remains of the cleavages in the bastite lie parallel with those of the augite; these pseudomorphs probably represent a rhombic pyroxene. The felspars are fresh and have symmetrical extinction about twin plains up to 27°, indicating the composition to be that of labradorite; they and the augite are very like the similar minerals in the usual type of the Karroo dolerites. There is much brownish interstitial matter, which was certainly glass once, but it is now no longer isotropic, though its constituents have not sufficient definiteness to be determined; it contains a few small felspars and augite grains. There is very little iron ore and no mica.

The Leeuw Draai intrusion has a wedge-shaped outline north of the river, and separates the Wilgenhout Drift beds from the Koras lavas for some four miles along a very probable fault; it is certainly intrusive and later than the lavas west of it. A thin section (1785) shows it to be a fine-grained rock with a large amount of semi-opaque devitrified glass, changed into an obscure mixture in which epidote grains are discernible, and also very small curved microlites. In this material as matrix there are very numerous, but small, grains of colourless augite, often showing prism and pinacoid faces, and small felspars which give symmetrical extinctions on the twin planes up to 25°, probably including members of the andesine-labradorite series. There are occasional small patches of chalcedonic silica playing the part of matrix. Some ilmenite and leucoxene are present. In the only slice cut there are no bastite pseudomorphs as in the Groot Drink and Koras intrusions.

The Koras rock is the smallest of the three masses so far as

it is visible on the north bank of the river; it occurs for a mile, or rather less, between the Koras sediments on the north-east and Kheis beds on the south-west, and it produced metamorphic changes in the former (see p. 56). In thin section (1794) it is seen to be very like the Groot Drink rock. There are numerous ill-formed pseudomorphs of bastite after a rhombic pyroxene in many cases partly or entirely surrounded by colourless augite. The augite is in grains and ophitic patches enclosing felspars. The felspars are more altered than in the Groot Drink rock and seem to belong to a less basic species than labradorite. There is much brown devitrified glass containing grains of epidote and chlorite, and also magnetite, with a tendency to form linear groups, but this feature is not nearly so well developed as in the Koras amygdaloids.

(3) Dolerites of the Karroo Type and Related Rocks.

Rocks more or less closely related to the well-known Karroo dolerites were found traversing the granite in the neighbourhood of Genesa, Morokwen, and Takoon, in the Kheis beds at Tsebe, near Kheis, and in the Karroo formation and the Zwart Modder beds from Witkop northwards, but it is only in the latter area, the north-western corner of the district described in this Report, that they are of much importance.

On Request, a farm on the north-west side of the Genesa Reserve, there are two wells sunk on a dolerite dyke, which has a course about W. 15° S. In thin section (1717) the rock is seen to be a coarse dolerite without olivine. The augite is very pale brown in colour, has occasional basal striation and is often twinned on (100); it forms irregularly-shaped pieces between felspars and has a tendency to be ophitic, but that structure is not well developed. The felspar is labradorite, or near it. There are small quantities of green hornblende and red biotite; the hornblende is usually in parallel position with augite. There is a considerable amount of magnetite. Some small interstitial patches of quartz-felspar micropegmatite are present.

On the Morokwen Reserve a few fragments of dolerite were seen a mile west of the large pan, but no outcrop was found.

On the Motiton Reserve, four dykes of a rock looking like the Karroo dolerite were seen. The longest one traverses both the granite and Black Reef quartzites in a N. 20° E. direction near Motiton. A dyke parallel to this one crosses the river south of the store at Takoon. This rock has the usual mineral composition of an olivine-dolerite, but under the microscope it presents (1630) a remarkable appearance owing to the felspar crystals enclosed in ophitic masses of augite, being arranged in radiating bunches. The olivine is abundant and contains magnetite in grains and an opaque mineral in minute flat dendritic-looking patches arranged parallel to the vertical axis. On examination under a high power, these growths, which are

only seen clearly in sections cut nearly perpendicular to an optic axis of the olivine, are found to be made of straight narrow blades, meeting at a point or along a median line. There is a small amount of red biotite.

Two other dykes near Takoon have a north-easterly course. They appear to be dolerites of the Karroo type, but have not been determined under the microscope.

On the farm Tsebe, south-east of Kheis, there are two broad dykes of a black dolerite-like rock running S. 10° W. through the Kheis beds, which strike S. 30° W. The eastern dyke is 100 feet wide and the western 150 feet. They were taken for ordinary Karroo dolerites in the field, but a thin section from the western dyke (1762) shows that the rock, though presenting many points of resemblance to the olivine-dolerites of the Karroo, has a much more basic composition, and is related to the rocks called augite-picrite. It consists of olivine, augite, biotite, magnetite, and a little felspar. The olivine is in colourless grains or ill-developed crystals, much cracked, and it contains magnetite in large and small grains and crystals; it also contains very small opaque scales and dendrite-like growths arranged parallel to the vertical axis, just like those in the olivine of the Takoon dyke. The augite has a very pale brown colour, and is in untwinned irregular pieces of considerable size, but it does not form ophitic masses; it encloses a few grains of olivine. The biotite is the strongly pleochroic red variety seen in many of the Karroo dolerites; it forms irregularly-bounded plates, often enclosing magnetite. The felspar forms irregular patches and is peculiar; it does not form good crystals with well-defined properties as in the dolerites; the twinning is irregular, the different parts of individuals or neighbouring individuals not being sharply separated in polarized light, but both albite and pericline twinning seem to be developed. The rock differs from the dolerites in the small amount of felspar present and the much greater quantity of olivine and red biotite.

A third dyke, of the ordinary dolerite type, was seen south-west of the picrite dykes on Tsebe.

The dolerites of western Gordonia were first seen at Witkop, but the first outcrops at the surface occur at Springbok Vley, some seven miles north-west of Witkop dam. At Witkop, a well has been sunk through the Dwyka tillite into dolerite, which lies 25 feet below the surface. This rock (1825) is a fine-grained ophitic dolerite of the usual Karroo type; it contains a few olivine grains, converted into serpentine, and some biotite, which is largely changed to chlorite. The rest of the rock consists of augite, labradorite and magnetite. The presence of dolerite underground a few miles further south is indicated by the metamorphic changes suffered by the tillite, described on p. 78.

On Springbok Vley, a sheet of dolerite, 80 feet thick, lies between Dwyka boulder shale below and hardened sandstones

forming the top of the hill on which the Trigonometrical beacon stands. The rock is deeply weathered into large spheroidal masses. It has caused the development of biotite in the overlying felspathic sandstone (1822).

The western corner beacon of Lang Vley is on a dolerite kopje, which seems to be an outlier of a sheet, possibly the same sheet as that on Springbok Vley, for it lies on Dwyka boulder shale. Unlike the sandstone-capped dolerite of Springbok Vley, it is not covered by a layer of weathered rock, but crops out in large rounded blocks loosely piled together like the granite and porphyry blocks in the kopjes of Upington Common and Koras. The weathered material has evidently been washed and blown away. The rock (1829) is a coarse olivine-dolerite. The olivine is abundant in large irregular grains, partly serpentinised. The augite is the usual very pale brown variety in large irregularly-shaped ophitic masses relatively to the felspar, labradorite, and it also encloses olivine. There is a considerable amount of magnetite and a very little red biotite.

On Opdam and the southern part of Onderste Narougas there are three outlying masses of dolerite like that of the Lang Vley beacon hill, and on the west side of the pan there is a long thick dyke-like mass terminating in a high kopje westwards, but the dolerite at the west end seems to be the remnant of a sheet.

Between the north side of Uitzak and Schepkolk there are many outcrops of a sheet overlying the shales just above the Dwyka shales with boulders. In the Eierdop hills a band of arkose, five feet thick (see p. 80) lies immediately below the dolerite. The dolerite at Uitzak krantz is over 40 feet thick, and in the Eierdop hills more than 50 feet. The prominent hill called Buiskop is an outlier of apparently the same sheet, but between the Eierdop dolerite and Buiskop there are outcrops of dolerite on the low ground, and these probably belong to a lower sheet lying at the top of the massive tillite, some 80 feet below the top sheet. This lower sheet is exposed again between the Eierdop hills and Haakschein Vley. In this area, where the dolerite forms bold outstanding ridges and also occurs on low ground, the contrast between the appearance of the rock in the two situations is very striking. The dolerite of the hills forms large rounded masses, with a very dark brown or black polished exterior; these are in contact with each other at a few points only, the interstices being either free from weathered rock or filled with brownish crumbling weathered dolerite. The dolerite on low ground has a more or less deeply weathered surface, and fresh specimens are difficult to obtain, though the low outcrops are occasionally marked by the occurrence of black boulders, the kernels of partially-weathered blocks. The explanation of this difference seems to be that on steep hills, such as Eierdop and the Lang Vley Kopje, the wind and rain have almost completely removed the products of weathering, leaving the sound kernels of the great blocks bounded by joint-planes

exposed. On the flat ground the decomposing debris cannot, as a rule, be removed faster than the drainage of the area permits; the wind alone cannot move many of the loose particles, and part of every fall of rain is retained in the accumulating debris and furthers decomposition. In the course of time such low-lying masses become more exposed to denudation, and then the sound kernels are left behind on the removal of the debris by wind and rain.

In the great pan on Kopjes Kraal and Wind Hoek there are two narrow ridges traversing the pan from one side to the other in a north-north-westerly direction and about 150 yards apart. The south-western dyke is 60 feet wide, and the north-eastern 47 feet wide, about a mile from the south-eastern end. The dykes are remarkably straight, though their course does not coincide with that of joints in the rocks penetrated at the surface—Zwart Modder beds. The dykes have a W. 30° N. course, and the only two noticeable joint systems run W. 20° N. and S. 10° W. The central portions of the dykes are deeply weathered, and the marginal rock, finer in grain, has withstood the action of the weather better than the coarser interior, so the two dykes have the form of troughs standing some 15 feet above the pan floor. The shale within a few inches of the dolerite is hardened, but the rock presents no other peculiar features to the naked eye. Thin sheets are given off from the dykes, and can be followed for some feet between the shales. Thin slices were cut from a 10-inch sheet (1833), and from the fine-grained marginal rock (1834). The rocks are of quite the same character. They are made up of small felspar laths, grains of calcite, flakes of a serpentinous mineral, magnetite grains, and some larger felspar crystals, labradorite. No augite or olivine are visible, but there are some rhombic pseudomorphs of calcite and magnetite, which look as if they represent olivine.

Traversing the Zwart Modder beds of the Sannah's Poort hills there is a dyke of dolerite about 800 feet thick, which was seen taking a north-north-easterly direction for some six miles from the German border.

No dolerites were met with in the Kuruman River or the Molopo, nor were boulders of that rock seen amongst the material thrown out from the wells along those river beds.

Blue-ground Pipe.

On the farm Witkop, in Gordonia, the existence of a serpentinous breccia of the "blue-ground" or kimberlite type has been proved in several prospecting holes. The rocks exposed at the surface round the prospecting holes are hard calcareous gravels and boulder beds of the Dwyka series, but the holes were dug in a pan-like expansion of a shallow dry valley running eastwards towards the Hygap, immediately below the dam east of the main road through the farm. Yellowish decomposed kimberlite con-

taining garnets, ilmenite, and diopside was met with from three to four feet below the surface, under the shelly limestones, gravels, and diatom earth described on a later page.

The kimberlite area is certainly over 100 yards in diameter, but its limits and shape are not known.

From two holes unweathered rock of the "hardibank" type has been taken, and three slices have been cut from specimens of this rock. One of them (1811) has a ground mass made up almost entirely of calcite, containing iron ores and perofskite. The iron ore is often in octahedra, and this is certainly magnetite, but there is also much irregularly-shaped material, which is perhaps ilmenite. The perofskite is in larger crystals than is usually the case in the Kimberley rocks; they are brownish in colour and the larger crystals are doubly refractive in part, the colours between crossed Nicols are grey-blue; the crystals do not behave uniformly throughout each individual. Crystals and fragments of crystals of olivine lie in this matrix; they are altered into greenish serpentine along cracks, and there are magnetite grains in the serpentine. The olivine is usually cleaved much more regularly than, for example, the same mineral in the olivine-dolerites of the Karroo. Irregular cavities in the section are filled with calcite and serpentine. The second section (1812) is very like the first, but it contains a few flakes of very pale biotite and rounded pieces of ilmenite, surrounded by adherent crystals of perofskite. The third slice (1813) shows a similar matrix, but in addition to the isolated olivines, there is a fragment of garnet-diopside-olivine rock; the garnet is changed round the periphery into a semi-opaque weakly birefringent substance, kelyphite; the diopside is very pale green in thin section. This rock fragment does not contain perofskite.

From the blue-ground and the yellow-ground thrown from the prospecting holes, I picked out lumps of dolerite, quartzite, red jasper, diabase or epidiorite, and pieces of Dwyka mudstone; also a fragment of a curious rock from which a slice (1827) has been cut. This rock is made of long blade-like areas of alteration products, including carbonates and a chloritic mineral, set in a ground mass of long radiating aggregates of colourless minerals, some of which is certainly quartz, and others seem to be felspars in an unusual form; there are also many very small aggregates of a highly-polarizing mineral, probably a carbonate.

Recent and Sub-Recent Deposits.

Throughout this district superficial deposits of various kinds, and often of considerable thickness, lie above the different formations described on the previous pages. They are of importance from the economic and the purely scientific points of view, for they often hide underlying rocks completely, and give the country a character quite different from what it would have were they not present, and they contain the evidence from which the

history of Central South Africa during an unknown length of time may eventually be read. At present very much remains to be found out, both about the conditions under which some of the deposits were formed and about the circumstances which governed certain changes in them.

As a chronological classification of these rocks cannot yet be given, they may be described under broad lithological groups, which, however, cannot be sharply separated from one another in practice. The groups are:—

1. Sands, etc.
2. Gravels.
3. Limestones, siliceous, and ferruginous rocks.

(1) Sands.

Nearly all the flat and gently-undulating ground in the district is covered with sand. Only along the Orange River and in the tract of country between the German border and the Hygap are there considerable stretches of hard ground on which the rocks frequently crop out; in the country just east of the Inkruip range there are also long strips of fairly hard ground, with occasional patches of surface limestone.

The country east of the Hygap is almost entirely covered with sand north of the Grond Neus stream and as far east as the Karree Boom hills on the south, the Kuie rocks further north, and the Kuis outcrops on the Molopo. This great stretch of sand is difficult to traverse, and during last year I skirted it only. From information given by a few people who have been through it, the course of the sand hills seems to be chiefly between north and west. From the Kuruman River I made several short excursions southwards, and after leaving the few irregular sand dunes near the river, where they generally lie roughly parallel to the river, the dunes have a course between W.N.W. and N.N.W. North of the Kuruman River, east of Matlapanin, the sand becomes flatter, and the low dunes are impersistent and apparently have no common trend. The Kuruman River itself is free from continuous stretches of sand, though it is occasionally invaded by small tongues of red sand, extending from high sand hills on the banks. The river bed is made of loose sandy limestone or white calcareous sand, entirely different in appearance from the red sand of the country to the north and south.

West of the Hygap the sand is broken up by many stretches of hard ground, but the wide belts of sand dunes near Abiam and between Springbok Vley and Middle Post make the road to Rietfontein a notoriously bad one to travel over.

Throughout this region the sand has a reddish tinge, owing to the presence of a small quantity of iron oxide; where the red sand reaches a river bed and becomes mingled with calcareous matter, it loses its red colour, and the same thing happens when

it forms part of the floor of a pan. Even in the harder floors of the "straate," the depressions or troughs between great dunes, the colour of the sand is often much paler than in the dunes themselves. In all these positions, the sand sometimes becomes wet, and remains so, for perhaps a considerable number of days or weeks; the bleaching is without doubt due to the reduction of the ferric hydrate in the presence of organic matter, chiefly plant remains.

In the case of some dunes west of Bloemfontein and near Skuynskalk the highest crests reach a height of quite 100 feet above the depressions on either side, but usually the height is less than 100 feet. The dunes in any particular neighbourhood may keep a straight course for many miles, but more often neighbouring dunes meet at low angles and branch again.

The dunes lie more or less parallel over considerable areas, but in the proximity of river courses, large pans, and hills, their course changes irregularly. Along rivers they often take a course more or less parallel to the bed. On the east and north side of the great Haakschein Vley the dunes are parallel to its edge, but the west side is free from sand, and the southern side nearly so. On the flanks of the hill ranges and isolated hills the sand is usually piled up to greater heights than it reaches elsewhere in the neighbourhood, but in several cases, as on the eastern side of Scheurberg and some of the Korannaberg hills, a high dune is separated from the hill by a deep trough.

East of a line joining the Kuie rocks and Karreeboom, the surface of the sand is less uneven than west of it. Though there are numerous short dunes, the sand tends to form very broad ridges, "bults," rather than well-defined dunes.

In the north-eastern part of the district, between the Kuruman River and Heuning Vley and Morokwen, the sand, though evidently of great depth and of the same nature as in the Kalahari, forms very extensive flats or gently undulating plains without dunes. In this part of the area there is also more bush and a more luxuriant growth of grass than to the south-west.

Throughout the district the sand is generally well covered with vegetation. It is only where tongues of sand stretch from the sand-veld down to the Orange River or the Molopo and Kuruman River that considerable expanses of bare sand are seen. The patch of bare sand round the outcrops of Witsand, described in last year's Report,[1] seems to be the only one of the kind in the southern Kalahari. Grass is less abundant on the sand near the German border than further east, and it seems to be generally more plentiful as one travels northwards and eastwards, as is also the case with the bush. The bush is thickest between the Mashowing River below Madebing and the Molopo, and

[1] Ann. Rep. Geol. Comm. for 1906, pp. 22-23. During a halt at Witsands in 1907 many pieces of the glass tubes, fulgurites, were found at Witsands, but they were all loose fragments.

there are many patches and belts between Morokwen and the Heuning Vley hills. West of Madebing the thick bush is confined to the banks of the Kuruman River, but scattered trees, especially the camel-thorn and 'Wit-gat" tree, occur throughout the sandy country traversed.

The most important effect of this vegetation, grass and bush, is to keep the sand in its place. It is evident to any one who travels through this country that, excepting the very small strips of bare sand mentioned above, the existing long and short sand dunes have long been in their present positions. Trees and stout bushes are found both in the troughs between the dunes and in various positions on the slopes and tops of the dunes themselves, so that in very many cases no considerable shifting of the crest of the dune can have taken place during the life of the tree. Near the German border the crests are sharper and have less vegetation than elsewhere, but even here the condition of the dunes is far more stable, as shown by the thickly-scattered tufts of coarse grass, than is the case with the white sand patches of Witsand and certain places along the south and west coasts of the Colony. During my journey the only places where the sand and dust were considerably disturbed by the wind were the flat ground near the Orange River and Haakschein Vley, where the size of the particles is smaller on the whole than in the sand veld itself, and where there are long stretches of ground almost or quite lacking vegetation.

The sand is chiefly made of quartz, but felspar grains seem to be very widespread. The grains are not markedly rounded, though the sharp edges have been somewhat worn down. Fragments of rock large enough to be recognisable as such are extremely rare throughout the sand-veld, except in the immediate neighbourhood of hills, and in a few places where surface limestone crops out in the sand. Even near hills like the Korannabergen, fragments of the rocks are confined to a zone a few hundred feet wide at the foot of the rock slopes, which invariably rise very steeply from the sand.

It is very difficult to get information as to the thickness of the sand. Such wells as have been dug are either in the laagtes or on patches of hard ground. On Pepani, south of Morokwen, three wells give information on this matter in an area which is outside the Kalahari proper, but which resembles the latter in several respects. The well near Mr. McKee's house is 131 feet deep, and the solid rock was not reached. The material thrown from the well is partly a pale loose sandstone, which crumbles readily; it shows no sign of stratification, but is traversed by numerous branching tubes, apparently formed round plant roots. This partly consolidated sand is associated with much loose sand and a small amount of harder material which occurs in irregularly-shaped lumps. From a piece of the harder rock a section (1849) has been cut; it consists of sub-angular grains of quartz, felspars, micropegmatite, tourmaline, magnetite, zircon,

and chert, cemented together by isotropic opal. The sand grains are evidently chiefly derived from granitic rocks, which underlie the sand in this neighbourhood. The hard rock differs from the other silicified surface rocks found during the journey in having no chalcedony in the matrix; all the silica of the matrix is still isotropic. There was not enough limestone at this place to attract attention, and the rocks collected do not contain enough carbonate of lime to give off a perceptible amount of gas when placed in acid. There are two wells in the Pepani laagte on the same farm; in the upper well 50 feet of loose sandy material of the same nature as that in the well near the house were passed through before the granite was met with; and in the lower well, about a mile below the first, 130 feet of the partly-consolidated sand were sunk through. The sandy material from these wells is just like the softer part of the rock near the house; it is traversed by the branching holes, which are sometimes slightly iron-stained, and no lamination is visible. No gravelly rock was met with in the laagte; the sand in the upper well rests directly on rotten granite, and in the lower well bed-rock was not reached.

It seems probable that the sandy material overlying the granite on Pepani is the result of long-continued accumulation of sand on the surface of the ground, and that the level of the surface has been raised 130 feet by that process.

(2) *Gravels and Alluvium.*

Gravels are not frequent in this area. From the north side of Upington Commonage, as far as Rietfontein, many of the patches of hard ground are thickly covered with pebbles and boulders, and appear, therefore, to be gravel, but these fragments have weathered out from the Dwyka tillite. The true gravels are confined to the river beds and their immediate neighbourhood.

Along the Orange River thin layers of gravel cover the ground in places up to 150 feet or more above the river. Thick layers are not exposed, and in many places it is obvious that the bed-rock is not deeply buried. The thickest gravel seen was in a ravine section on Kheis, which showed six feet of gravel with a loose limestone matrix. The pebbles in the gravels are chiefly of local origin, Kheis quartzites or other rocks according to the situation, but there are always many from the country above the Langebergen, Matsap and Griqua Town rocks especially. Below the outcrops of the Koras beds boulders and pebbles derived from the Koras conglomerates (purple amygdaloid and red porphyry) are very conspicuous.

There are stretches of alluvium at many places between Kheis and Upington, on the north or right bank of the river. Near Upington water is taken over the alluvium by a long furrow, and the gardens there are noted for their fertility. The alluvial deposits are confined to a narrow belt, for the river has a rather

steep fall in this part of its course, and the solid rocks crop out either on the bank or within short distances of it. The dry climate of the district, however, gives great importance to the alluvial ground within reach of artificial irrigation from the river.

In the Hygap valley below Zwart Modder there are thick layers of gravel from 20 to 30 feet above the present stream bed. The valley here is from 1,000 to 1,500 yards wide, and is limited by steep cliffs of the Zwart Modder series. The gravel is exposed in places to a depth of 20 feet. It is made of well-rounded pebbles of various rocks, evidently derived in great part from the Dwyka series, with a sandy calcareous matrix. In places the matrix is quite hard, and the rock becomes a conglomerate with limestone matrix.

The limestone cliff on the left bank of the Molopo at Zoutpans Puts (five miles below Lieutenants Pan) do not contain any gravel, though a few scattered pebbles occur in the limestone.

No gravel was seen in the Witdraai well, nor in two other dry wells in the lower part of the Kuruman River; the first gravels met with on a journey up that river were seen about 35 miles from its confluence with the Molopo, where a calcareous conglomerate with pebbles of chalcedony, quartz, red jaspers, banded magnetic jaspers, chert, and lavas from the Ongeluk series, forms the river bed in places. The limestone matrix of this consolidated gravel is just like the white surface limestone exposed very frequently on the banks and in the bed of the river.

At Witkrantz there is a well, 35 feet deep, in the bed of the Kuruman River; the well is sunk through sandy limestone, with occasional layers of pebbles of the same kind as those mentioned above from the calcareous conglomerates lower down the river. The bed rock has not been reached in this well.

On the Mashowing, 16 miles above its junction with the Kuruman River, gravels appear on the surface some 50 feet above the bed; they consist of fragments from the middle and lower groups of the Griqua Town series. In places they are cemented together by a limestone matrix. These rocks are again found in section on the steep slopes on the sides of the Mashowing and Kgogole at Madebing, and at places the fragments are angular. The limestone has here undergone more or less silicification, and will be referred to again.

(3) Limestones, Siliceous, and Ferruginous Rocks.

Surface limestones of various kinds are found in all parts of the district under consideration, though in the sand-veld considerable intervals may separate the outcrops. The surface quartzites, on the other hand, were only found in the north-western part of the area, betwen the neighbourhood of Genesa and that of Kuis; they were not met with in the Kuruman River

below Tsenin or in the sand-veld south of the Molopo and west of the Korannaberg.

All these rocks are essentially the result of the cementation of sand by carbonates or silica, with or without an appreciable quantity of iron oxide, but while some of them have been formed directly by the deposition of the carbonates or silica around the sand grains, others are evidently the result of a subsequent replacement of the earlier carbonates by silica.

A precise sub-division of these rocks according to their modes of origin cannot yet be made, nor can they be classified according to age.

In many parts of the district there are more or less extensive deposits of whitish limestone, containing grains of sand and fragments of rock. In the country between Morokwen and the Heuning Vley hills these limestones are particularly abundant, just as they are further south in Kuruman and Griqualand West, on the continuation of the same belt of country formed by the Campbell Rand series. In this area the surface limestone is obviously formed by deposition from water rising to the surface and evaporating there, leaving behind the material carried up in solution from the underlying Campbell Rand limestones. The outer crust is generally distinctly harder than the rock beneath it, and the limestone encloses more or less sand and, occasionally, pieces of chert.

In no other situation, except along the river beds traversing the sand-veld, is so much surface limestone seen as on the Campbell Rand beds.

This kind of surface limestone crops up very frequently between Morokwen and Konkwe, but west of Konkwe the outcrops become less abundant, and in parts of the area between Konkwe and Heuning Vley nothing but sand is seen for many miles together. Where the Mashowing traverses the Campbell Rand beds, the sand is also very prevalent; the turfaceous limestone outcrops are confined to a belt near the river.

The rivers which enter the sand veld from the east, *i.e.*, the Molopo, Kgogole, Mashowing, and Kuruman, all traverse the Campbell Rand beds before reaching the sand veld, and therefore, whatever water flows down them from behind the Heuning Vley-Kuruman hills brings some limestone in solution. Wherever the banks of these rivers are not covered by sand, some limestone is seen, and usually it is the only hard rock exposed.

The sections along these rivers will be described separately.

The Molopo.—The only part of this river examined above its junction with the Nossob was the 12 miles between Kolingkwane and Kuis. Approaching this part from the south, one travels over a sand-covered plateau, on which the sand forms irregular undulations, but not the long dunes characteristic of

the Kalahari south of the Kuruman River. Outcrops of surface limestone are first seen from two to three miles south of the Molopo, and they become more frequent towards the edge of the steep slope which bounds the river. The descent from the plateau to the river bed is very steep, usually steep enough to be called a cliff, and good sections are frequently exposed. Fig. 11 represents a short length of the cliff on the left side of the river near the Mogogobe water-hole. The Matsap quartzites here form the base of the section, and they are overlain, first by a few inches of quartzite rubble, and then by 90 feet or less of various limestones and siliceous rocks. The only indication of bedding is given by the layer of gravel, which has a maximum thickness of 12 feet here, but which thins out. Some hundreds of yards down the valley a similar gravel fills a hollow in the Matsap beds, and is covered by limestone. The pebbles in the gravel are of various rocks, chiefly from the Griqua Town and Campbell Rand beds, but also quartzites from the Matsap and a few granites and amygdaloids of the Pniel type, both of which may perhaps have come from the Dwyka in the immediate neighbourhood. The matrix of the gravel is mostly compact, sandy limestone, but there are patches of silicified rock which stand out more or less prominently from the limestone on the exposed surface. The silicification appears to have taken place capriciously, partly along narrow veins in the limestone, now filled with chalcedony, and partly as a general replacement of the carbonates by silica. In appearance there is very little or no distinction between the limestone and the silicified rock as seen by the naked eye; they have to be scratched or hit with a hammer to be distinguished. The thick mass of almost structureless sandy limestones forming the greater part of the cliff has a pinkish colour below and a yellowish or white colour above. The pink rock in places forms large rounded masses in the white limestone; one of these lumps at first looked as if it were a boulder derived from the pink rock; a careful examination of several such masses showed that they were not of that nature, but that they are masses of limestone slightly different in colour from the enclosing rock, but not sharply separable from it. Siliceous masses of a whitish colour frequently occur in the upper 30 feet of the section; they are irregular in shape and do not have sharp boundaries. The limestone in their vicinity is traversed by thin veins of chalcedony. Thin sections of these rocks have not been prepared, for the rocks are very like those described below from a similar position in the Kgogole laagte near Madebing. These silicified rocks were not seen near the base of the superficial deposits, though on account of the short time spent at the locality this fact does not imply that they never occur there.

Throughout the limestone grains of sand are frequently seen; in the harder parts the rock breaks through the grains rather than round them.

The uppermost few feet of the section are harder than the

rock just below, and on the steeper parts of the cliffs many irregular caves are formed on that account.

The Mogogobe section is typical of the Molopo valley between

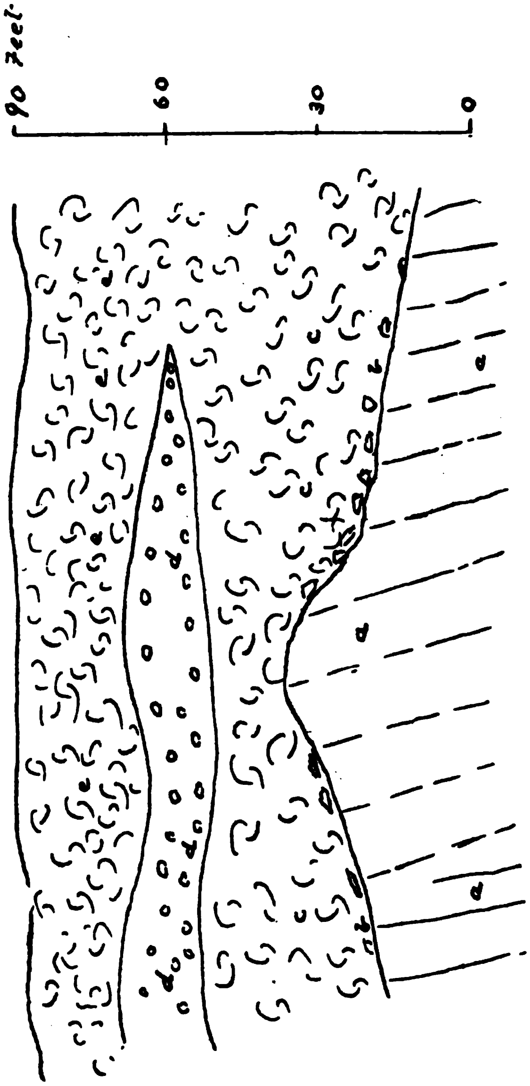

FIG. 11.—Section seen at Mogogobe on the left bank of the Molopo. *a, a*, purple Matsap quartzites dipping west; *b, b*, rubble of quartzite with loose limestone matrix; *c, c*, pinkish limestone with occasional pebbles; *d*, conglomerate with limestone or chalcedony matrix: the limits are not really so well defined as in the sketch *e*, whitish limestone with large masses of chalcedonised rock.

Kolingkwane and Kuis, though the details vary. In places the hard Matsap quartzites rise nearly to the top of the cliff, and are overlain by only a few feet of limestone. Generally the superficial rocks are thicker where they overlie the Dwyka than where the Matsap beds crop out.

No fossils were found in the limestone of the cliffs, though some small snail shells and pieces of bone occur in the gravelly limestone exposed within the valley near the level of the top of the water-hole.

The sections on either side of the valley and some 500 yards apart are very similar, but this does not involve the assumption that the deposits exposed once stretched across the valley and have since been cut through by the Molopo. It is more likely that the hardening materials have been formed continuously within the sand or gravel forming the bank at any particular time, and that the steepness of the cliffs is due to the top hard layer, which always caps the limestone, protecting the immediately underlying rock during the continual backward cutting of the cliff by wind and rain. I looked for a suitable side ravine, which might afford a lengthy section of the superficial deposits at right angles to the river valley, but I did not find one. There are several short steep ravines, but they are covered with loose fragments of limestone, and do not give the required information.

Near the bottom of the valley there are frequent exposures of gravel with limestone cement and of sandy limestone. These exposures are small, but they show bedding; layers of gravel are intercalated with layers of more or less sandy limestone; a thick section of these rocks would present a very different appearance from that of the cliff at Mogogobe.

The Kgogole River.

The Kgogole River rises south-west of Genesa on a sand-covered granite plateau, and after being joined by the Mokgalo laagte enters the Mashowing at Madebing. A short part only of the valley has been examined.

Near the Kgogole Reserve, on the granite region, no limestone is seen on the banks of the laagte, but quartzites and ferruginous rocks crop out along some four miles of the right bank about 40 feet above the floor of the laagte. They are whitish and yellow-brown stained cavernous rocks with a maximum exposed thickness of four feet. The varieties richest in iron occur at the base of the exposures, but there is a very gradual change from the darkest to the lightest coloured rocks, which are found at the top. The rock is a quartzite, white, yellowish, or brown, traversed by irregular cavities, which are lined with chalcedony, opal or a thin layer of iron oxide, and when freshly exposed by being broken through, sand falls from them. In places a roughly parallel structure is given to the rock by the cavities being arranged with their longer axes lying nearly flat, but it is a very indefinite structure. The rock passes under sand a few yards away from the top of the steep slope to the laagte. No quartzite was seen in a corresponding position on the left bank of the laagte. No limestone appears at the surface near the

quartzite, but some soft limestone is thrown from a well in the laagte in which granite is exposed, and a small amount of limestone occurs in thin layers between shells of weathered granite in a shallow ravine on the left side of the laagte, where there is no quartzite.

At Tlaping, in the Mokgalo laagte, soft shelly limestone (with *Physa*) is taken from a well, and fragments of the usual hard surface limestone are found on the surface north of the laagte together with pieces of surface quartzite like that near Kgogole, but exposures of the latter rock were not found.

In the Kgogole laagte about half a mile above its junction with the Mashowing there are good exposures of the limestones and quartzites on the left side of the valley. They are interesting also, because it is obvious, from the position of outcrops of the solid rocks here (Ongeluk volcanic series), that the super-

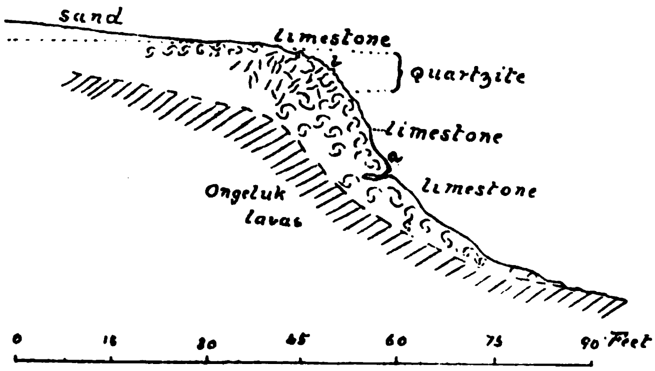

FIG. 12.—Section on left side of Kgogole laagte half a mile above its junction with the Mashowing ; *a* and *b*, spots from which the rock slices, 1837 and 1838, were taken.

ficial deposits are merely a thin coating laid over the rock slope, as represented diagrammatically in fig. 12. The outline of the solid rock there given is not observable in section at any one place, but from the position of outcrops on the same side of the laagte within a few hundred yards of the locality it is certain that the outline fairly represents the facts. The Ongeluk rocks are exposed at the foot of the slope and they are overlain by limestone containing numerous fragments of lava and vein quartz. The lava fragments are weathered, the outer zone is red to a depth of nearly half-an-inch in some cases, within this the rock is bluish green. The breccia is continued up the slope for some 10 feet, when the fragments become scarce, and the rock is a sandy limestone of various degrees of hardness; the softer parts have, in places, been removed, giving rise to holes. A thin slice (1837), taken from a rock just above the hole shown in the section, fig. 12, is seen under the microscope to consist of grains of quartz and a few small pieces of Ongeluk lava, set in

a rather coarse-grained calcite matrix. In a few places a small amount of chalcedony is seen between the crystalline particles of calcite. The chalcedony in this rock is not present in sufficient quantity to be observed by the unaided eye, but the amount increases upwards until the rock appears to contain no carbonates. The quartzitic rock proper occupies a vertical height of about 10 feet on the slope, and is covered by surface limestone, which soon disappears under sand. The upper limit of the quartzitic rock is more sharply defined than the lower, but there is a gradual transition between it and the overlying limestone. Two slices were cut from the quartzite (1838 and 1851). They are crowded with sand grains, chiefly of quartz, with a few felspars and other minerals, including a grain of tourmaline. These lie in a matrix of small grains and rhombohedra of calcite and much silica. The calcite is mostly packed closely round the sand grains and then follows opal, chalcedony fills the remaining part of the interstices. A large patch of chalcedony encloses a central coarsely-crystalline area of calcite. Some patches are coloured brown by iron oxides. Another slice (1839) from the quartzite near the place from which the other two were taken consists of sand grains cemented by opal and chalcedony, and part of a pebble of chert, with pseudomorphs after a cubic mineral.

These silicified rocks seem to have been formed by the replacement of limestone cement by silica, which first has the properties of opal and subsequently changes to chalcedony. It is quite clear that all stages of the replacement are found within a short distance of each other in one and the same rock mass. It would be important to find out in this or a similar locality whether a section taken, say, 200 feet behind the slope, under the sand, shows a similar set of changes in the rocks lying upon the Ongeluk beds. At present there is no opportunity for such an observation. The partly silicified rock at this locality is very like a rock mentioned by Dr. Passarge from the bottom of the water-hole at Inkauani Pan[1], and which he calls "hard chalcedony-sandstone," and says it may be either a directly silicified sandstone (eingekieselter sandstein) or a silicified calcareous sandstone (verkieselter kalksandstein). A slice from a specimen of this rock (1861) given me by Prof. Kalkowsky is very like (1838) described above from the Kgogole laagte.

Matamatobo Laagte.

No outcrops were met with in the short section of this laagte, which I examined. The floor of the laagte south of Pepani is a firm grey soil; small pieces of loose textured limestone are thrown up by burrowing animals. Surface limestone is exposed

[1] "Die Kalahari," p. 518.

by rain washing out the wagon track in the tributary laagte from the S.S.E. which leads to the Kgogole Reserve.

On the farm Shooter's Hill there is an exposure of ferruginous and siliceous rock at the junction of two branches of the Matamatobo laagte. It is a reddish earthy rock with irregularly-shaped masses of harder material, due to cementation by iron oxides or silica, or both. There are irregularly-shaped cavities in some of the hard masses lined with opal. The mineral fragments enclosed in the earthy or hard matrix and large enough to be recognised with the help of a lens are quartz.

The Mashowing River.

The first superficial deposits of interest in the Mashowing Valley are seen near Masilibitsani. The bed rock here is granite or gneiss, which crops out frequently in the river bed and on the flat or gently-sloping plain to the north and south of it. To the south of the river the granite disappears under sand; along the river, as far down as the Black Reef escarpment of Garaphoane, sand is the prevalent covering on the south side, and there are very few outcrops of limestone. To the north of the river opposite Masilibitsani there is a mile-wide slope of surface limestone and gravel, broken only by a few large outcrops of granite and quartz-porphyry; the limestone slope rises to about 40 feet above the river, when it is succeeded by a steeper slope of limestone and a krantz of the same rock, 10 feet high, above which lies a low krantz of quartzite without pebbles, and this quartzite passes under sand. The section in Fig. 13 represents the facts at this locality. The river bank in places is a vertical surface of

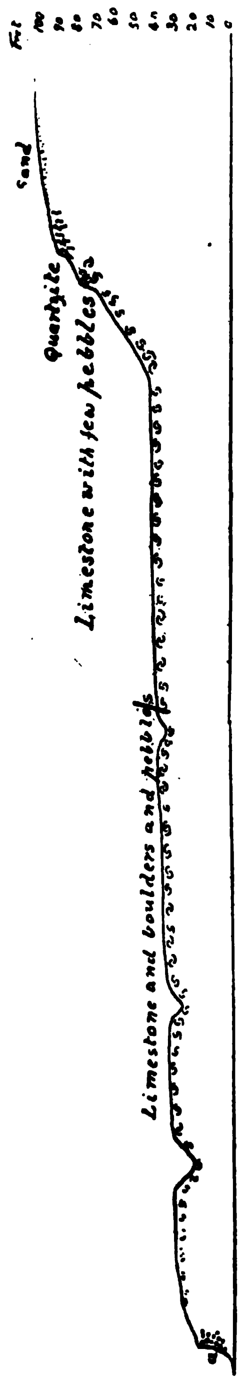

FIG. 13.—Section across the flat north of the Mashowing, near Masibibitsani. *a*, Gravel with loose limestone matrix seen on the river bank. Length of section, 1 mile.

gravel with a loose sandy limestone matrix. The limestone on the slope above contains boulders and pebbles of Black Reef quartzite, granite and gneiss, quartz-porphyry, diabase, and amygdaloidal lava, but not of the surface quartzites such as are exposed to the north; fragments of these quartzites are only found on or at the foot of the steep slope between the outcrop and the plain. The plain is cut up by ravines, in which sections through the limestone with boulders are exposed to the depth of about 10 feet. So far as observed, no silicification has taken place in these limestones, but they have not been minutely examined. The limestone of the steep slope contains a few pebbles. The passage upwards into the quartzite is obscured by debris, and by the fact that both the limestone and quartzite are much harder outside than within; in each case after breaking away the outer hard blocks near the limit of the two, one finds a loosely compacted sandy material, apparently without much lime in it and probably no siliceous cement. The quartzite outcrops are very cavernous, and are like the rock described below from the Genesa laagte. The outcrops extend nearly 12 miles down the right side of the valley, but they disappear below the sand before the Black Reef escarpment on Garaphoane is reached. Quartzite of the same kind and in a similar position reappears on the right bank on the west side of Garaphoane, and extends 12 miles down the river as far as the Magonat Reserve. The ground between the quartzite outcrops and the river bed is occupied by limestone and gravel, as at Masilibitsani. The limestone becomes of importance on the left or south bank some eight miles below Garaphoane. It extends from the bed of the river to a height of 50 or 60 feet above it, but there are no definite layers or isolated outcrops of quartzite at this level on the left bank, though a quartzite like that above Garaphoane appears at the surface about a mile south of the river on Pietquane, and is soon lost under sand. Both on the right and left banks irregular patches and layers of siliceous rock of a different type from the top quartzite occur in the tufaceous limestone exposed in the banks and on the slopes above them below the Linopen Reserve. These rocks are found at short intervals many miles down the river, to within 16 miles of its junction with the Kuruman River, *i.e.*, over more than 50 miles of its course. A thin slice (1731) from the farm Olney, on the south bank of the Mashowing, together with notes made in the field, affords the following description of the silicified rock. The rock is largely a very fine-grained limestone, containing a few grains of quartz. This compact limestone has been divided up into various-sized pieces by cracks running in various planes, but the largest and most persistent cracks are roughly parallel to the upper surface of the rock, *i.e.*, to the surface of the ground. These cracks are filled with calcite, or silica, or both, and they give the rock a brecciated appearance. The minerals filling the cracks were first deposited uniformly on the walls, and the successive layers conform to the

irregularities of the walls; but where the cracks are more than 2 mm. wide, part of the space is filled with material deposited without reference to the shape of the walls. Generally the smaller cracks are filled with calcite alone, but there are small cracks, less than 2 mm. long, entirely filled with chalcedony, or first by a layer of opal and the rest by chalcedony. The opal evidently changes to chalcedony, for cracks looking precisely alike are found in the one case to have an outer layer of opal, and in the other to consist of chalcedony alone. In a few cases the larger cracks are filled with calcite alone, generally with a mixture of calcite and chalcedony, and again with chalcedony alone. The calcite in this mixture does not occur in small crystals, but in irregularly-shaped crystalline grains of large size, very much larger than in the limestone itself. In certain irregularly-shaped areas of considerable size there is a mixture of chalcedony and calcite grains of very small size, like those of the limestone. These areas are in part sharply bounded and in part grade into a transitional rock, with more calcite and less chalcedony; this transitional rock passes into the ordinary limestone. In these areas we see stages between the limestone and an almost completely silicified rock.

On the Mashowing at Madebing a curious breccia partly covers the outcrops of the Ongeluk volcanic rocks on the steep slope above the river, on its right bank. In one place 10 feet of the breccia were seen in section. It consists of fragments of quartz and volcanic rocks set in a sandy siliceous and ferruginous matrix; most of the iron is in the form of limonite, but haemetite is frequently seen. Some of the breccia is clayey and soft.

On the left bank about four miles below Madebing there are good exposures of limestone and silicified rock. In general, they resemble those in the cliffs at Mogogobe and in the Kgogole laagte at Madebing. The lower exposures are limestones; the silicified limestone forms an inconstant band near the upper part or at the top of the steep slope; it passes laterally into ordinary limestone, in which no silicification can be detected in the field.

The Kuruman River and the Matlowing.

On the Matlowing River, near Tsenin, there are banks of white sandy limestone, 14 feet high. Silicification was not noticed in this rock, but a large block of a peculiar-looking pebbly silicified rock was found in the river bed. The pebbles are of chert, quartz, and blue dolomite or limestone from the Campbell Rand beds. In thin section (1732) the matrix is seen to consist of chalcedony and calcite. The pebbles are generally surrounded by a thin coat of chalcedony, and the rest of the matrix is chalcedony with a small quantity of calcite in rhombohedra. The chalcedony of the interspaces often has a spherulitic structure. I was unable to learn the source of this rock, but it probably came from no great distance.

The usual white surface limestone with a hard crust on the outside is met with very frequently along the Kuruman River, from the junction of the Matlowing down to the Molopo, but no part of it was found to be silicified. One or other bank was frequently examined between Tsenin and Upper Dikgathlon and again between Lower Dikgathlon and the Molopo, in all a distance of nearly 150 miles; of this distance more than half was travelled by daylight. Two miles below Gasese there is a section showing eight feet of calcareous rock resting on a reddish calcareous clay, of which 10 feet are exposed. The reddish clay is different from any of the rocks seen elsewhere in this district; it is certainly a form of superficial deposit. It shows no sign of lamination nor any pebbles or fossils. The calcareous rocks commence with a boulder bed of chert, lava, and banded ferruginous jasper boulders set in a sandy limestone; it varies in thickness up to a foot, and a thinner layer of gravel limestone rests on it. From three to four feet of white unbedded sandy limestone lies on the gravel, and then comes a bed, one foot thick, of gravel limestone, thinning out in places. The section is completed by from two to three feet of white unbedded sandy limestone. No shells were found in this section. It seemed to me that the only parts of this rock certainly laid down by the river are the gravels. The white limestone was probably formed by the cementing together of sand by carbonate of lime from the river water, and the sand was, in part at least, blown sand on the river banks. The higher layers of gravel were, on this view, laid down, during changes of the river's course in flood times, on previously deposited drift sand. No explanation of the reddish calcareous clay is forthcoming, but it would resemble some of the loess-like deposits found on the Kaap Plateau if more clay and some lime were added to the latter.

At Lower Dikgathlon the limestone and gravelly limestone is penetrated by a well to 60 feet below the river bed. Below this place the greyish white sandy limestone very frequently crops out on the banks at various heights up to 10 feet above the bed. The rock often occurs in layers from 6 to 12 inches thick, which can be followed for a few hundred yards; two such layers may occur together. They are made of whitish sandy limestone with many winding tubular cavities filled with sand; but no shells were found in them. The limestone outcrops in the river bed often contain shells; the species have not yet been determined, but some of the genera are *Corbicula*, *Physa*, *Planorbis*, *Ancylus*. The limestone is occasionally stained by iron oxides. A thin section from an iron-stained outcrop (1836), about 35 miles above the junction with the Molopo, is seen under the microscope to be a compact fine-grained limestone, with a general slight yellow colour, containing grains of quartz. It is traversed by thin veins of some coarsely crystalline and colourless calcite.

The Hygap River.—This is the name given to the lower part of the Molopo, below the junction of the Kuruman River. On the left bank at Zoutpans Puts there are great exposures of sandy limestone, extending from the river bed to a height of 60 feet above it. The upper surface is very hard, but I found no veins or patches of chalcedony or opal in the rock either near the top or lower down. The rock contains a few rounded pebbles of quartz and chalcedony from amygdaloidal lavas. No shells or bones were seen in it. Below these outcrops, which make a prominent krantz, the course of the river bed is marked for many miles merely by whitish sand. In the lower part of the Hygap, between Bloemfontein and Ghous, the only limestone seen forms the matrix of gravels, which have been described in a previous section.

In a shallow valley leading towards the Hygap on Witkop, there are some interesting surface deposits. A calcareous variety of the Dwyka tillite crops out near the valley, and probably underlies the whole of it, excepting that part where the blue-ground pipe is. One of the prospecting holes exposes a good section through the surface deposits. Lying upon the yellow decomposed Kimberlite there are eight inches of loamy material, then come six inches of very light calcareous diatom earth with *Physa* and other fresh water shells, upon which lie about 18 inches of gravel with numerous shells of *Unio* and *Corbicula*, which is covered by a foot or less of whitish calcareous soil. The diatoms and shells collected at this place have not been determined, but the locality was visited by Prof. Schultze, of Jena, during 1905, and, from the collection he made, 34 species of diatoms were determined by Herr Reichelt, and 10 species of mollusca by Prof. Boettger.[1] The mollusca are:—

Corbicula fluminalis (Müll.)
Corbicula radiata (Phil.).
Pisidium cf. *langleyanum*. Melv. Pons.
Unio (Hyridella) fissidens. Bttgr.
Planorbis (Hyraulus) natalensis. Krauss.
Planorbis cf. pfeifferi. Krauss.
Isidora parietalis. Mousson.
Isidora natalensis (Krauss).
Ancylus (Ferrissia) stenochorias. Melv. Pons.
Ancylus trapezoideus. Bttgr.

Dr. Boettger states that this collection of mollusca indicates that a moister climate formerly prevailed in the region, and that this difference in the climate makes it advisable to class the deposits with the "Pleistocene." He says that *Unio fissidens* is the only species that can with comparative certainty be regarded as extinct, and that *Ancylus trapezoideus* may be

[1] "Aus Namaland und Kalahari," by Dr. L. Schultze, Jena, 1907, pp. 706-708.

so. He remarks the presence and abundance of *Corbicula fluminalis*, a Nile species.

Herr Reichelt determined the diatoms in Dr. Passarge's specimens from the Kalahari, and 17 out of the 34 species determined from Witkop are mentioned by him in the list on pp. 770-773 of "Die Kalahari." But he states in "Aus-Namaland, etc.," p. 706, that the Witkop collection is a peculiar flora of slightly brak-water origin, and is not like any assemblage of species collected by Dr. Passarge. They do not throw any new light on the geological age of the deposit. He detected siliceous sponge spicules in the Witkop rock

The valley expands into a pan, under the sandy surface of which there is a yellowish limestone containing *Physa* shells. This is the only pan met with in Gordonia which contained fossiliferous limestone, but it differs from the typical pans in being an expansion of the old valley, and not an isolated depression. In a thin section of this rock (1826) the outlines of the shells are less obvious than in the hand specimen on account of the recrystallization of the carbonate of lime in them and to the want of clear distinction between it and the calcite of the matrix. Diatoms are abundant.

Since these fossiliferous rocks of Witkop were formed there has been no considerable change in the surface features; the deposits have neither been denuded nor buried to any noteworthy extent. The white calcareous sand found on the sides of the depression no doubt shifts from time to time, but the water brought down by the valley has not had time to bury or denude the fossiliferous rocks. There is now a dam across the valley, and, owing to the impervious nature of much of the ground above the dam, a considerable amount of water comes down during rains. It seems to me that the general features of the neighbourhood and the circumstances under which the fossiliferous deposits are found do not justify the use of the term "Pleistocene" in connection with them. Dr. Boettger is not very sure about the extinction of the mollusca, and the mollusca of Bechuanaland and Gordonia do not seem to have been fully studied as yet. The temporary existence of the great vley at Abiquas Puts and its fish in 1894 shows that the mere presence of a layer of richly-fossiliferous deposit may not indicate anything that can be properly called a change of climate.

In those parts of rivers or laagtes, surveyed during last year, lying entirely to the east of the Black Reef escarpment, the laagtes between Tlakgaming, Genesa, and Morokwen, surface limestone is often seen, though it is not developed to the same extent as in the laagtes to the west. So far as the bed rock of this district is known it is granite or gneiss, with an occasional dolerite dyke.

In a dry well, two miles below the Tlakgaming fence across the Doorn laagte, small irregular nodules of white sandy lime-

stone occur in grey sandy soil, of which there is a thickness of three feet overlying whitish granite wash. The lumps of limestone are evidently nodules formed where they are found. On Stonehenge and Distin, along the Tlakgaming laagte, surface limestone crops out on the road where the traffic has removed some of the soil, and on the south part of Distin some eight feet of soft limestone with hard portions in it are exposed in a well. The well is in the laagte. The limestone contains *Physa* shells. A thin section (1714) shows a semi-opaque base of limestone, in which no structure is visible; there are grains of quartz, felspar, and epidote, and crystalline calcite fills irregular spaces and the interior of *Physa* shells. The siliceous skeletons of diatoms are visible in places, though they are difficult to see on account of the presence of the limestone.

In a well in the Genesa laagte on Donegal, 20 feet of white sandy limestone were found to overlie the granite, and the same rock crops out at many places in the laagte between the Donegal well and the Wegdraai well. About two miles above the latter surface-quartzite crops out on the right bank; forming in places a vertical face six feet high, and extending some 200 yards back from this outcrop before being quite covered by sand. These outcrops are continued some five miles up the laagte. The rock seen in the outcrops is a quartzite penetrated by ramifying passages up to three inches wide, after the manner of the holes in a sponge. The holes are filled with sandy earth behind the face of the outcrops. In thin section (1715, 1716) the rock is seen to consist of various-sized grains of quartz, felspar (chiefly microcline), magnetite, tourmaline, epidote, zircon, and apatite, cemented by a siliceous matrix, mostly chalcedony, though some opal is present. The larger grains are rounded, the smaller more angular. Though the felspar grains are generally recognisable in ordinary light by their slight turbidity, due to alteration, they are not much altered, and some of them are as clear as the quartz. There is no limestone seen above the quartzites or on the slope down to the laagte. This rock would seem to be one of the directly silicified sandstones (eingekieselter chalcedon-sandstein of Dr. Passarge). When lumps of the quartzite are broken up, the apparently solid portions are found to contain irregularly-shaped patches and veins of bluish chalcedony; these are sometimes hollow, and in such cases there is a layer of vitreous opal on the surface of the chalcedony. Neither the chalcedony nor opal was seen lining one of the branching tubular cavities mentioned above. Towards the upper surface the rock becomes more ferruginous, and in places it is indistinguishable from the usual lateritic ironstone, *i.e.*, it is made of grains of sand cemented together by brown oxide of iron.

I could not find a well or other exposure showing the thickness of this rock under the sand of the plateau behind the river bank. In general appearance the rock seems to be the edge of a layer under the pale red sand of the plateau. Its absence from the

left bank of the laagte and from the wells on Request, though a few inches of ironstone were passed through by the upper of the two wells, would indicate that the quartzite is only an isolated patch. Its mode of occurrence on this river is like that of the surface of quartzites of the south of Cape Colony. Its variable character within short distances is also a point of resemblance to the latter rocks.

In the granite country north and east of the Black Reef escarpment, from Takoon to Morokwen, little limestone is seen outside the laagtes, though wells sometimes prove its existence where it would not be expected. On the farm Bosh Buit, between Genesa and Takoon, the decomposed granite was met with 17 feet below the surface; it is covered by 10 feet of earthy material, with some calcareous matter in it, and this is followed by four feet of sandy limestone, above which are three feet of sandy soil. The country here is covered generally with pale red sand. Where a road descends a slope towards a laagte in this region, a sandy ironstone is usually exposed by the washing away of some of the sand by rain water.

Between the Korannaberg-Langeberg ranges and the Scheurberg-Inkruip-Kuie line of outcrops, surface limestone is seen in places where the sand is absent or less abundant than elsewhere. The limestone is a sandy rock, hard with softer limestone below the surface. In places, as to the east of Inkruip, outcrops of Matsap quartzite are seen in the same neighbourhood as the limestone, and consequently the rock underlying the limestone is probably the quartzite. In other localities, as to the south-east of Gamotep, where there is much limestone, the nature of the underlying rock is quite uncertain.

In the country between the Hygap and the German border, surface limestone is frequently seen lying on the Dwyka tillite, where there is little or no sand. This limestone oftens contains pebbles and boulders weathered out of the Dwyka.

PANS.

Pans are found in many parts of the district, but they are especially abundant in the area occupied by the Dwyka on the western border.

In the granite area of the north-east pans are few and usually small. The Klein Chwaing Pan was described in last year's Report.[1]

The pan at Morokwen is the largest that was seen in the north-east of the district. Granite crops out in the pan, and at several spots round it at a higher level than the floor of the pan. Limestone forms a bank round part of the pan, and it has undergone partial silicification; small veins and patches of chalcedony may be found on breaking open the limestone. The pan has a small quantity of salt in it mingled with the calcareous sandy

[1] Ann. Rep. Geol. Com. for 1906, p. 82.

material forming the surface of the floor. The natives collect a little salt from it.

The other pans seen in this region are small depressions in the sandy ground with a harder material on the floor than the surrounding sand.

I had an opportunity of visiting the farm Water Pan, described by Mr. du Toit in the Report for 1905, p. 156, and as the green quartzite noted by him is of considerable interest, a few more details of its occurrence and nature are worth recording. The pan itself was full of water at the time of my visit, but the quartzite is exposed in two wells. In one of these the decomposed granite is met with 20 feet from the surface, and above it lie eight feet of green quartzite with a capping of 12 feet of rather loose limestone with *Physa* and other fresh water shells. In the second well the granite surface is 23 feet down, and there are three feet of quartzite and 20 feet of limestone on the top. A thin layer of quartz and quartz-porphyry pebbles separates the limestone and quartzite. The slope of the granite surface is towards the pan. The quartzite contains pebbles of quartz-porphyry. A thin section (1844) shows chips and grains of quartz, felspar, zircon, magnetite, and chert set in a siliceous matrix, which has a yellowish tinge under the microscope. Most of the matrix is scarcely anisotropic, but parts of it are chalcedony. Much of the matrix looks as if it was made of chalcedony, of which the individual particles are extremely small. There are cracks filled with a yellow, rather highly birefringent substance with radial structure.

On the area occupied by the Campbell Rand beds, between Morokwen and Heuning Vley, there are many small pans, depressions on the surface of the hard tufaceous limestone seen so frequently in that area.

The large pan called Heuning Vley lies immediately at the foot of the escarpment of the Griqua Town series. It is about $3\frac{3}{4}$ miles long in a north-north-easterly direction, following the strike of the Griqua Town beds, and about a mile wide at its widest part. The Griqua Town beds in places descend to the floor of the pan, but do not crop out on the floor itself; they form low krantzes in the middle and southern parts of the western side of the pan, and small springs of fresh water issue from the base of the outcrops. Where there is ground higher than the floor of the pan between its western border and the outcrops of Griqua Town beds, masses of hard ferruginous breccia of fragments of Griqua Town beds are often seen appearing through the sandy soil, but no limestone was met with on the western side. At the south end of the pan, the place of the ferruginous breccia is taken by a breccia with limestone matrix; this rock is soon covered by sand. The eastern bank is sandy, with a little limestone in the southern parts. On the eastern side the lowest rock seen is a whitish limestone, which passes

upwards into a greenish quartzite. Both these rocks contain small angular and subangular fragments of Griqua Town rocks up to two inches in length. A thin section of what was collected as a piece of the limestone (1840) proves it to be mainly composed of a matrix of small grains and rhombohedra of calcite, enclosing sand grains of quartz, felspar, and tourmaline. There are small patches and veins of chalcedony in the limestone; the chalcedony preserves the outlines of some of the original rhombohedral calcite by the presence of zones of very minute opaque particles. A section (1841) from a quartzite from the same place shows rounded grains of quartz, felspar (microcline and plagioclase), chert, and an igneous rock largely made of plagioclase, set in a cement of chalcedony. Calcite is only seen in one part of the slice, where there is a small amount scattered through the chalcedony.

The floor of the pan is made of a white sandy calcareous mud, which is hard when dry, but the wind can move dust and sand from its surface, and the place is undoubtedly undergoing a gradual reduction in level owing to this action. A slight efflorescence of salts, in very large part common salt, is found in patches on the western side of the pan, and the water which gives rise to swampy areas on that side of the pan is salt, although the water which issues from the springs mentioned above tastes quite fresh.

In the middle and northern part of the pan there are many outcrops of limestone and siliceous rocks projecting above its surface. Some of the outcrops are small and isolated, but they mostly form groups from 20 to 100 yards long and of various widths of about the same extent. The rocks stand up as much as two feet from the surface, and are obviously undergoing denudation. The limestone and quartzite often occur together in one outcrop. A section (1850) from one of these outcrops shows a few quartz-grains set in a matrix of granular calcite, with small patches and streaks of chalcedony. No diatoms were seen in this or the other limestone examined from Heuning Vley, but they may be masked by the calcite, and a complete examination of the rocks has not yet been made.

Both the limestone and quartzite at the level of the floor of the pan have a green colour, which becomes brighter upwards, and the tops of the quartzite outcrops are almost white. These highest quartzites are glassy and brittle rocks, evidently containing little or no carbonate.

The eastern pan at Heuning Vley has a white calcareous sandy mud floor, without outcrops of limestone or quartzite. There are a few small fragments of limestone on the surface. It is surrounded by greyish white sand.

Between the W.N.W. dunes in the country between the Black Rock and Korannaberg there are small ill-defined pans, sometimes with a red sandy limestone and mud floors. These hold water for a few days after rain. Similar pans are of frequent

occurrence in the sand-veld further west, but they have hard sandy mud floors only. These pans, though they may contain water for several days or a few weeks after rain, do not seem to be recognised locally as of the same value as the better defined pans, nor are they indicated on the farm diagrams. They are always elongated in the direction of the neighbouring sand dunes, and the floor is usually covered with small bush. During my journey from Upington to Rietfontein, several of these pans between Abiam and Springbok Vley had held water for more than a week.

In the sand-veld just east of long. 22° E. there is a line of pans extending from Kuie Pan in the north to Kakoup in the south, a distance of over 30 miles; though there are wide intervals between the pans, the linear grouping may be due to the geological structure of the area, for the line probably follows the area occupied bv the Kheis series. To the east and west of it the Matsap beds, which are on the whole better adapted to resist weathering than the Kheis series, probably come in at no great distance.

Kuie Pan was about four miles long from north to south and some 1,000 yards wide at the time of my visit, when it contained more water than for many years past, though it was possible to cross it dry-footed by a band of schist and limestone outcrops a mile and a half from the north end. This pan is undoubtedly a hollow in the Kheis schists, which crop out all round it so frequently that there is no room left for a depression filled with sand or other superficial rock, marking an old valley. To the east and north the Kheis beds form a few prominent kopjes, and to the west they occur in a long ridge, which rises 200 feet or more from the pan floor. At the south end the outcrops are fewer and smaller than elsewhere, but they were three feet above the water level at that time. The depth of the water seemed to be very slight, less than 12 inches where it was directly observed. After a northerly wind had been blowing for a few hours, the water was driven southwards, exposing a wide stretch of the pan floor at the north end. The quartz-schist on the pan floor and from a well on the east side is of a bright green colour; when the rock can be followed from the level of the floor to a height of one or two feet above it, the green colour is lost. A great part of the floor free from water in April, 1907, was made of the Kheis beds, and sandy limestone covered most of the remaining portion. A sandy calcareous mud is seen where the hard rocks are absent, and it probably forms the greater part of the area covered by water during my visit. The limestone has a greenish colour in many places. It occurs in large flat masses lying on sandy mud, or directly attached to the rock. Three slices were cut from limestones forming outcrops just above the water at the south end of the pan. (1746-8). They show the rock to be a compact limestone, containing grains of quartz, felspar, chlorite, and epidote, and that it is traversed by

veins of more coarsely crystalline calcite. There is no chalcedony or other form of silica, except the quartz of the sand grains.

Lying upon the dyke rock intrusive in the Kheis beds of Kuie Pan (described on p. 84) there are patches of thin limestone. A slice (1753) from this rock contains many pieces of plagioclase and altered felspar, augite, and green decomposition products derived from the dyke rock, together with quartz grains of the usual sort, set in a limestone matrix. Another slice (1753) was taken from the junction of the green schist with the overlying limestone. The two rocks are so firmly joined that it is difficult to break the rock along the junction with a hammer. Seen under the microscope, the limestone is a fine-grained compact rock, but it has some cracks in it partly filled by calcite; the rest of each crack is empty. This matrix contains many angular quartz grains, evidently derived from the schist, white mica flakes, and a few grains of magnetite and felspar. At the upper limit of the schist the quartz grains are slightly displaced, and the interstices are filled with calcite; throughout the 3 mm. of schist seen in the slice, the calcite has made its way downwards between the quartz grains, especially along planes perpendicular to the surface between the schist and limestone, planes which are also those along which most of the mica lies. The water in the pan was very slightly salt at the time of my visit, but I was told that in a few days' time it would be too salt for cattle to drink, owing to the concentration of the salts by evaporation of the water.

To the east and west of Kuie Pan thick sand soon covers both the limestone and the schists. To the north the sand also covers the rocks, but there are outcrops of schists without limestones at Sand Kuie and further north. To the south sand is also abundant, but there are outcrops of limestone towards the Malanie pans. A thin section (1745) from a spot about three miles south of Kuie Pan shows a granular calcite matrix, enclosing rounded and angular grains of quartz, felspar, tourmaline, and magnetite. There are also lumps of more compact limestone enclosed by a coarser matrix, as though the surface limestone had broken up and had become re-cemented by freshly-deposited limestone. From the appearance of many outcrops of surface limestone, it seems that the rock breaks up into various-sized pieces when exposed, and should the outcrops again be covered with sand and the process of deposition be continued, a brecciated rock would result.

The two Malanie pans lie east of the schist outcrop called Malanie Kop, and the same rock appears at the surface again immediately west of the northern pan. The pans are covered with a sandy calcareous mud, with many small fragments of limestone. Limestone of the usual surface type, without chalcedony, crops out round the pans and between them. This limestone forms wide slabs, often broken up into pieces from 2-24 inches across, about 1 inch thick. It does not form a bed

lying at one level, but conforms to the gentle slope of the ground at each spot. The ground slopes towards the pans, and the 700 yards of ground separating the two pans slopes towards the pans from the middle of the rise; it is also made of slabs of limestone with some sand, and the limestone slabs slope with the ground.

Some ten miles of low sand dunes with occasional outcrops of surface limestone in the troughs separate the southern Malanie Pan from Rooi Pan, which is oval in shape, about 800 yards long from north to south by 500 wide. The floor of Rooi Pan is a sandy mud; much of it was covered by water at the time of my visit. Surface limestone crops out at many spots on the west side of the pan, and in fewer places to the north and east. Between Rooi and Gamotep Pans surface limestone frequently crops out amongst the sand. Two thin slices (1743, 1744) from this locality show a brecciated structure, owing to the inclusion of a more compact limestone by a limestone made of larger grains of calcite. Both kinds enclose numerous grains of quartz, quartzite, chert, magnetite, and epidote.

Gamotep Pan lies rather more than a mile south of Rooi Pan. It is about 3,000 yards long by 1,000, or more, wide. The greater part of the floor was covered by water at the time of my visit, but the dry area consisted of a greenish brown sandy calcareous mud. The water was fresh enough to be used for drinking purposes. On the west side of the south end of the pan there is a bank through which a small ravine has been cut, exposing about 15 feet of loose cavernous sandy limestone lying immediately beneath the sand. Neither this rock nor any of the limestones mentioned from the Kuie Pan-Kakoup line were found to contain any shells. A few rounded and sub-angular lumps of vein quartz and quartz-schist lie on the surface of Gamotep Pan.

On the north-west side of Gamotep pan red sand seems to be encroaching upon the floor of the pan; elsewhere the sand near the more or less well-defined edge of the pan is of paler colour than further away from the pan.

Owing to the generally observed association of groups of large pans with the Dwyka series, I specially looked out for boulders that would indicate its proximity or former presence along the line of country where these pans are, but the only rocks foreign to the neighbourhood were small pieces of the banded jaspers from the Griqua Town series and bits of chalcedony, and these were undoubtedly carried there by natives, either in the form of chipped arrow-heads or as pieces of rock for their manufacture. Many well-shaped flakes of small size were found near the Gamotep water-hole (at the rock-hole, not the pan). Though small chips, rarely over an inch in lengh, are numerous in this area, larger implements of the same kinds of rock were not seen though to the east of the Langebergen, along the Orange River above Upington, and at Witsands west of the Langebergen, the large implements are often found.

The Kakoup Pan lies about two miles east of the north end of the Inkruip Range, between high red sand dunes, which run W. 20-30° N. The pan is rather ill-defined, but is about a mile long in the W.N.W. direction, and some 500 yards wide at most. The lowest part of the pan, filled with water at the time of my visit (April 20th, 1907), is made of a sandy calcareous mud. A pit dug in the north-west end of the pan exposes two feet of loose tufaceous limestone lying on a green calcareous sandstone. No shells were seen. The green sandstone is traversed in all directions by branching tubes from a quarter to half an inch wide. The section has a bedded appearance owing to the alternation of softer layers with two harder and apparently more calcareous beds. A thin slice (1742) from one of the hard limestones shows many angular and rounded grains of quartz, chert, quartzite, magnetite, tourmaline, zircon, and a few pieces of felspar, set in a medium-grained matrix of calcite. No trace of subsequent silicification was noticed in the rocks exposed nor in the thin section.

Though the underlying ancient rocks cannot be seen at all of the pans in the Kakoup-Kuie line, there can be little doubt that they belong either to the Kheis or the Matsap series, and that there are no rocks there which can supply the considerable amount of calcite seen in the surface limestone of the area. It is an interesting problem to find the source of the carbonate of lime, but at present the information as to the contour of the surface of solid rocks between the pans and the country east of the Langeberg is too scanty to decide the details of the course of the surface drainage, which, however, is certainly in a general sense westwards towards the sand-veld and southwards towards the Orange River.

Excepting the bedded rock seen at Kakoup, the limestones are devoid of stratification, and they have probably been deposited by evaporating water either within the sandy ground outside the pans or at or near the surface of the muddy pan floors. There is no evidence that any of these pans were formerly more constantly filled with water than is now the case. Had that been so, one would expect to find a molluscan fauna in some of the limestones; but shells were only seen in the limestone of Waterpan in Vryburg, in the Witkop Pan—an expansion of a valley—and in limestones in the Molopo and Kuruman River beds. Where these shells were found, they were so abundant that their presence could not escape notice, and in spite of the fact that the other pan limestones were somewhat cursorily examined, I think it unlikely that they contain shells.

In the south-eastern part of the sand-veld, from Kuie Pan to the Orange River, there are pans without any limestone associated with them. These pans are rather like the pans between sand dunes previously mentioned, but the former have more or less circular outlines, and would appear to be generally better defined than the latter. The floors are made of sandy mud. One

of these pans lies about three miles from Kuie Pan, south of the road to Inchwanin, and there are several of them between Inkruip, Scheurberg and the south end of the Langebergen.

In the country occupied by the Dwyka series, between Upington and Rietfontein, pans are abundant. On Areachap, Rooi Puts, and Steenkamp Puts there are many small pans up to 100 yards in diameter. They are nearly circular shallow depressions in hard pebbly ground. Though there may be an occasional outcrop of grey surface limestone near the pans, this rock is not a prominent feature, as it is in the Kuie group. Outcrops of the Dwyka beds are only found where the rock is a hard limestone, but the variety of pebbles at the surface always indicates the presence of the tillite. In the case of a pan by the road-side on Areachap, a well section within a few yards of the pan proves that the tillite descends many feet below the pan floor.

The north-western part of Gordonia is remarkable for the number and large size of the pans in it. In many cases the Dwyka series crops out very near or in the pans, so that they are probably situated entirely or partly on that group of rocks. In other cases, only sand and other superficial deposits are seen in their proximity.

The Abiam Pan was the first of the large pans seen. The Dwyka tillite occurs to the north, west, and south of it, and there is a considerable amount of surface limestone. The pan floor is a calcareous sandy mud.

Abiquas Puts is of particular interest, because it received water from the Kuruman River in 1894. The old course of the water was down the Hygap, but that bed had been blocked by drift sand, and the water was diverted to Abiquas Puts. The Dwyka series underlies the surface to the north-west of the pan, but sand dunes occupy most of the country round it.

The Narougas Pan is a flat surface of about nine square miles of grey sandy mud, surrounded on the north, south, and east sides by red sand-dunes. On the west side there are outcrops of the Dwyka series and dolerite, but no outcrops were seen on the floor of the pan. It is separated from the Skuynskalk Pan by a belt of red sand-dunes. The Skuynskalk Pan is about five miles long and over three wide; it is elongated in the direction of the trend of the sand-dunes in the neighbourhood, about east and west. When I crossed it, there was water along the southern side, but the depth was not over three inches. The floor of the pan is of sandy mud. In places the surface was sun-cracked, and the top film of mud had a smooth surface, which reflected light well. This film was often divided up into small areas by the cracks, and curved up at the edges, exposing a more sandy substratum. The mud of the floor of this pan is more clayey and less sandy than usual, and evidently shrinks considerably on drying. The pan is surrounded on all sides by red sand, but wells on the north side prove that the rock there

belongs to the Zwart Modder beds, and not to the Dwyka series.

The Kopjes Kraal Pan is about nine miles long in the north-easterly direction, and five wide. It lies partly on the Dwyka series, and partly on the Zwart Modder beds. The floor is a light-coloured sandy mud, and in the northern half this mud is very thin, allowing the joints in the rocks below to make themselves seen on the surface, and in places the rocks are exposed. A remarkable feature is the occurrence of two parallel dolerite dykes, stretching across the northern part of the pan in a west-north-westerly direction. These dykes have not been cut to a level surface with the enclosing rock, and stand up from the floor like walls. The pan is surrounded by sand-dunes on the south, east, and north-east, but there is probably a krantz of the Zwart Modder beds, of which part is exposed at Blaauw Krantz, limiting both Kopjes Kraal Pan and the still larger Haakschein Vley, on the east, but the greater part of the krantz is buried under sand. It is likely that this krantz represents a surface feature of Dwyka times, for a patch of pebbly Dwyka shale (see p. 80) was found three miles north of the Wind Hoek dam below the outcrops marking the extension of the Blaauw Krantz cliff.

On the top of the Blaauw Krantz section there are seen about 50 feet of sandy limestone and sand. The rock lying immediately upon the Zwart Modder beds is a soft sandy limestone, riddled with winding passages filled with sand; this rock is about four feet thick. It is followed by some 30 feet of similar but looser rock, and this in its turn is overlain by five feet of harder limestone which passes under sand. In thin slice (1835) the rock is seen to be a compact limestone, with veins and patches of more coarsely crystalline calcite in it; these two kinds of limestone enclose grains of quartz, felspar, magnetite, garnet, and zircon. At the south end of the krantz the limestone can be seen passing downwards under the sand, and in isolated patches nearly to the level of the pan, but they do not appear on the pan surface.

Haakschein Vley is the largest pan in Gordonia, and probably also the largest in Cape Colony; it is 14 miles long in a north-north-westerly direction, and six miles wide at the broadest part. The western side is on the Dwyka series, seen in occasional outcrops and in a few holes dug in the hard mud ground west of the pan's edge. The southern edge is on shales and sandstones of the Zwart Modder series, and the same rocks are seen occasionally on the eastern side amongst the sand-dunes, which there limit the pan, and again in frequent but small outcrops on the floor of the pan itself. The greater part of the floor of the pan is madeof a pale-coloured sandy mud. Both on Haakschein Vley and Kopjes Kraal Pan there are patches of white salts on the surface, near the edges of the pans; these layers are very thin, and do not completely cover the sandy mud. On the hard ground, partly bare outcrops of the Dwyka series and partly

hard mud, on the west side of Haakschein Vley, there are stream channels which lead storm-water to the pan. They evidently bring considerable quantities of mud into the pan, but in spite of this, the pan does not seem to be silting up. Mr. Rautenbach of Skepkolk, who has probably known Haakschein Vley longer than any other white man, told me that the patches of bare rock on the floor of the pan have increased in size and number during the past 40 years. The only means by which material can be taken out of the pan is the wind. I happened to cross the pan on a rather windy day, and the amount of very fine dust in the air on that occasion was very great. At times one could not see trees or other conspicuous objects 300 yards away, yet the wind was not strong. No vegetation grows on the pan floor, and the red sand from the east and north, if ever it tends to invade the pan, cannot get a permanent resting-place there. The rocks which crop out on the floor are not very resistant to the great diurnal changes of temperature, and do not appear to retain a surface long enough to receive a polish from the action of sand and dust blown over them. This is even true of an outcrop of dolerite seen about two miles north of the Wind Hoek dam; the surface of the dolerite is crumbly, and at least the felspar is considerably decomposed. Probably the salts, which must be present in small quantity throughout the pan floor, aid the processes of weathering. The occasional pebbles of quartz and chalcedony, probably derived from the Dwyka tillite, show distinctly the effects of wind-borne sand, though the "dreikanter," more or less sharp-edged facetted pebbles shaped by that action, were not observed.

Between Kopjes Kraal Pan and the Salt Pan, nine miles to the south-east, there are many long red sand-dunes, trending about W. 15° N. The sandy limestone seen east of Kopjes Kraal Pan soon disappears under the sand, but a precisely similar rock crops out round the Salt Pan and for some three miles north-west of it. Two miles north of the Salt Pan there is another pan, about a mile long and 500 yards wide, with a visible amount of salt mixed with the surface of hard sandy mud. There are no outcrops of hard limestone round this pan, but at the south-west corner there is an exposure of about three feet of laminated sands, white, grey, and yellow, in layers up to two inches thick; the white layers are harder than the others, and contain more lime. The layers slope towards the pan. The exposure is only four or five feet long. No shells or other fossils were seen. A remarkable feature in this pan was the enormous number of dead locusts and beetles on the floor. In places they were so arranged in belts that it was obvious that they had been in the pan when there was some water in it. The Salt Pan is well known in the district for the amount and excellence of the salt on its floor. At the time of my visit there was a solid crust of salt from one to two inches thick lying on black salt sandy mud. Water was met with three inches below the

surface. The salt crust is divided up into polygonal areas, analogous to the areas enclosed by cracks on dry mud flats. The cracks in the salt crust are filled with salt, whiter and containing less impurities than the crust itself. This very white salt forms low ridges, up to half an inch high, over the cracks, and it is evidently deposited by water rising along the cracks and evaporating at the surface. The pan is nearly three miles long, and about a mile wide at the broadest part. The salt crust extends almost to the edge of the pan. There is no apparent explanation of the large amount of salt in this pan, the only one on the west of the Hygap which contains much. It does not seem to receive water from a larger area than, for instance, Haakschein Vley. Another salt pan called Matsiman exists to the east of the Hygap in this region, but I have not seen it.

Analyses were made of the salt from the two pans by Dr. C. F. Juritz, Senior Government Analyst; the figures are:—

	No. 1.	No. 2.
Calcium sulphate	Very faint trace.	Very faint trace.
Magnesium sulphate	Trace.	Trace.
Sodium sulphate	.48	.62
Sodium chloride (common salt)	98.55	98.31
Moisture	.01	.29
Sand (insoluble matter, estimated by difference ...	.96	.78
	100.00	100.00

No. 1 is the salt from Rautenbach's Pan; No. 2 that from Matsiman Pan. The resemblance between them is very striking, and so is the percentage of sodium chloride. The Matsiman sample was obtained from a native at Wit Krantz, on the Kuruman River, who had recently come from the pan. The other sample was taken from the crust on Rautenbach's Pan. It cannot represent the composition of all the salts held in solution by the water which deposited it, for water was found three inches below the surface, so the most soluble constituents were probably still in the water. The very small amount of calcium sulphate, a substance of wide distribution in pans and in the soil of areas without efficient drainage, is probably to be accounted for by the facts that the deposit at this pan is thick, very likely thicker than the salt crust taken out, and the calcium sulphate is much less soluble than common salt, and would have been deposited earlier, in the black sand or below it.

Water Supply.

The country described in the previous pages is probably on the whole the worst watered area in the Colony, so far as water for domestic purposes and stock is concerned. The actual rain-

fall is not known, except at Upington (8.67 inches a year, an average of 9 years before 1894)[1] on the southern border; since 1894 the rainfall does not seem to have reached 5 inches. The country generally seems to be remarkably well covered with grass and bush, but this abundant vegetation is confined to the sand; on the hard ground near the German border, along the Orange River, and in the small areas found amongst the sand, the vegetation is of the Kàrroo type, short, sparsely scattered bush with drought-resisting leaves. The explanation of the difference probably is that in the sand-veld there is a thick layer of damp sand, the depth of which changes but slightly from year to year, and which supplies the trees throughout the year with water, possibly the grass also. In the hard veld there is no such damp zone at a moderate depth; the ground seems to be dry generally to a considerable depth, and then there is the layer of ground water which supplies wells when tapped.

From inquiries made on the journey, the usual experience of those who dig for water in the sand-veld is that damp sand is met with at a depth of 8 or 10 feet below the surface; but the water is never in sufficient quantity to collect in a well; after passing through many feet of damp sand, dry sand is again encountered, and usually no further water is found, even though the well be sunk to bed-rock.

The sand of the sand-veld allows rain water to penetrate the ground rapidly, and yet is not coarse enough to let the moderate or small quantity received run through to bed-rock or a less pervious layer; the water is thus held in the sand by capillarity.

The only successful wells met with west of the Langeberg-Korannaberg range were sunk in the river beds or in the hard ground near the German border. It is probable that water in moderate quantities could be obtained anywhere along the Kuruman River below Dikgathlon, at depths of less than 100 feet. The existing wells, except that of Wit Draai (80 feet) are not deep enough. The Witkrantz and Matlapaning wells at the time of my visit gave a few buckets of water a day, not enough for a small team of oxen, and the Lower Dikgathlon well was very weak; if these wells were deepened, they would very probably yield much more water than they now do.

The conditions in the Molopo above its confluence with the Nossob seem to be more favourable than those of the Kuruman bed, for water at a few feet below the surface is got between Kolingkwani and Kuis. Both in the Molopo and Kuruman Rivers the reason why deep wells have not been made probably is that the well sinker would have no security of tenure; otherwise the value of the water for stock and its sale to users of these routes to the German border would certainly have induced people to make satisfactory wells.

Both the Dwyka and the Zwart Modder beds afford water in

[1] A. Buchan; A Discussion of the Rainfall of South Africa, etc., 1897.

the country near the German border; the wells are, of course, sunk on the patches of hard ground; those seen by me were less than 100 feet deep. The water from the Zwart Modder beds is generally less brak than that from the Dwyka. There seems to be little difficulty in getting moderate supplies of water in the hard veld; west of the Hygap the country has a very small slope, and in spite of the scanty vegetation, the amount of water which runs off is probably small in proportion to that which evaporates at the surface or sinks underground along joints. It is likely that the conditions are more favourable along the German border than east of the Hygap, where the patches of hard ground are few and surrounded by thick sand, for the latter to a great extent prevents the rain-water from reaching the solid rocks from which it might be obtained by wells.

The sand-veld holds water in a way that is favourable to vegetation, but not to the supply of wells, and in the case of the hard-veld the conditions are reversed.

GEOLOGICAL SURVEY OF PORTIONS OF MAFEKING AND VRYBURG.

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I. INTRODUCTION.

The area examined is a continuation in a westerly direction of that mapped in 1905, and includes a triangular portion of country between Pitsani, Genesa, and the Molopo, extending westwards to a little beyond Morokwen.

As the work progressed, it became evident, owing to the great development of the superficial deposits, that the production of a map showing the solid geology would be almost an impossibility. The map (sheet 52) which has been issued shows therefore as far as possible the actual exposures of the formations only, but the approximate limits of some of the areas occupied by certain of the formations are indicated by means of broken lines.

Opportunity was taken of the improved transport facilities in revising wherever the routes permitted the boundary lines of the previous survey. This was especially the case along the belts occupied by the Kraaipan formation, where the mapping was done on a somewhat larger scale and where the work was aided by the presence of new prospecting shafts and trenches.

Physical features.—The whole of this area consists of rather monotonous, slightly undulating country, with an almost imperceptible fall towards the north. It is traversed by a number of shallow depressions or laagtes—they can hardly be termed river-valleys—which extend towards the north or north-west and unite with the Molopo. Between each pair of laagtes the ground rises from 100 to 200 feet and forms a low bush-clad rise or "*bult*."

From Genesa there is a gentle fall towards Morokwen, after which the country rises and culminates in a chain of low hills, the highest of which is just about 4,000 feet above sea-level. From this ridge to the Molopo there is a fall again amounting to about 500 feet. Over this wide area the soil is always a light yellowish or pinkish-red sand, supporting a long coarse grass and dotted over with shrubs and thorn trees. Towards the Molopo the vegetation becomes thicker, and from Mabul onwards there is a belt of dense bush, from eight to 15 miles in width, which is continued on the north bank far into the

Bechuanaland Protectorate. This forest-belt should prove very valuable, for there are large numbers of Camelthorn trees *(Acacia giraffae)*, besides other acacias, which afford good timber. Beyond Morokwen there is a large tract occupied by the Hakdoorn *(Acacia detinens)*.

The rainfall of this area is apparently somewhere about 20 inches annually but owing to the sandy nature of the soil it is only for a short time in the wet summer season that any water flows in the rivers.

Geology.—Granite and gneiss is the underlying formation over the greater part of the area; beyond Morokwen the rocks of the Transvaal system appear. Superficial deposits conceal large tracts.

The formations can be arranged as follows:—

	Superficial Deposits	Sand, limestone, surface-quartzite, red marl, etc.
Transvaal System	Griqua Town Series (Lower)	Banded jaspers, ironstones, and cherts.
	Campbell Rand Series ...	Limestones, dolomites, cherts and shales.
	Black Reef Series ...	Quartzite, arkose, and conglomerate.
	Kraaipan Formation	Banded magnetic rocks, cherts, jaspers, and slates with interbedded diabase, amygdaloid, rhyolite, and hornblende-chlorite- and calcareous schists.
	Granite and gneiss.	
	Schists in the granite and gneiss.	

(The wavy line denotes an unconformity.)

There are a few basic dykes penetrating these formations. A dyke on Saints' Rest, near Genesa, and another in the dolomite north of Morokwen are ophitic dolerites of the Karroo type. Four dykes crossing the Mosita valley on Gemsbok Pan, Groot Gewagd, and Klip Pan are diabases of pre-Karroo age.

II. The Schists in the Granite.

Along the Setlagoli River, on Steil Hoogte and Krom Draai, the granite has inclusions of hornblende schists, like those previously recorded from Mafeking.[1]

Some of the larger masses are almost entirely of hornblende and are well foliated. The inclusions are seamed by threads and veins of granite, aplite, and pegmatite, and portions have frequently been fractured across the foliation planes and faulted. In a few places beautifully-banded composite gneisses have been produced, with foliation planes striking a little west of north.

[1] Ann. Rept. Geol. Commn. for 1905, p. 210.

On the Madeakham Native Reserve, a well has been sunk in biotite-gneiss, containing inclusions of amphibolite traversed by veins of granite, aplite, and pegmatite. Banded gneisses were also struck in a well on the farm Venter's Rust far down the Genesa laagte.

Petrologically these 'schists" are characterised by an abundance of sphene, usually accompanied by epidote. Microcline, so charactertistic of the granite, is absent, and the felspars are orthoclase and plagioclase.

Whether these rocks were originally of sedimentary or igneous origin is not clear, for the occurrences in Mafeking are not on a large enough scale to decide this point. As similar rocks are found in the Prieska granite[1] it is possible that further evidence will be obtained in the area south of the Orange River.

The banded composite gneisses indicate in all likelihood that these rocks already possessed a foliated structure at the time of their invasion by the granite.

Partly digested inclusions, the true nature of which can still be recognised, are not uncommon. A section (1712) of one of these from a patch in the granite one-and-a-half miles east of Setlagoli shows the following minerals under the microscope:— Quartz, orthoclase and plagioclase, chlorite (representing biotite and hornblende), epidote, and abundant sphene. The structure varies from schistose to granulitic.

It seems most likely that some of the banded granulitic gneisses in Mafeking represent the ultimate stage of metamorphism and absorption of these schists by the granite, for usually they are rich in sphene and epidote, while there is a deficiency of microcline felspar.

III. The Granite and Gneiss.

The granite is rarely exposed in the area between Mosita and Morokwen, but it has been struck in a number of wells and boreholes, and its extent must be considerable. Small exposures are found at Genesa and in a few of the shallow valleys, which are so characteristic of this part of Bechuanaland, while the rock is also exposed in a couple of pans at Morokwen. There are wells in granite or gneiss at Tlakgaming and Khudungkwani, while in the First Railway Grant to the north, granite has been struck in all boreholes. Along the Genesa and Tlakgaming laagtes there are a number of wells, *e.g.*, Wegdraai, Chwabe, Reitzdale, Donegal, Inverness, as far north as Venter's Rust. Beyond the last named, the Black Reef and Campbell Rand formations appear, and the approximate limit of the granite can be fairly well defined.

Between Khudungkwani and Mosita there are several wells in granite, *e.g.*, Kalk laagte, Bont Bok, Wilde Als Put, and

[1] See p. 163.

Doorn Bult, but the area to the north, including the Western Railway Grant (in Mafeking) is almost without wells, or else the superficial deposits have not been penetrated in well sinking.

The granite varies considerably in character, but is generally a medium-grained pale-pinkish variety with either muscovite or biotite mica; pegmatite veins are common. The strike of the foliation planes varies generally between north and north 30° east. Sometimes the rock is massive, at other times gneissic, while not unfrequently there are alternations of foliated and unfoliated granite.

Porphyritic varieties, with large crystals of pink felspar, occur on Woodrust, just north of Genesa, and again at Morokwen, where there are extensive outcrops at the western end of the pan. These varieties recall the granites of the Motiton Reserve.[1]

IV. The Kraaipan Formation.

Upon following the Mosita belt northwards past Logaging, an excellent section was found along the Setlagoli River, where the various members of this formation have been exposed on the banks of that stream. Over wide areas the exposures of this belt usually consist of the more or less isolated outcrops of the hard magnetic and cherty rocks, separated by stretches of red sand. Here, however, the softer strata, which alternate with the harder beds, are well exposed and consist chiefly of volcanic rocks more or less sheared, together with quartzites and calcareous schists. The section is so important that it will have to be described in detail (fig. 1); by its means many difficulties in the interpretation of the succession in the case of other exposures of this formation have been removed.

The lowest beds are seen along the river about half-a-mile below the homestead on Logaging and again just behind the house. The granite on which these beds must rest is not exposed, the rocks towards the west being hidden by sand and tufa. The rocks forming zone 1 are green diabases and amygdaloids and sometimes breccias, with thin layers of magnetic quartzite interbedded between some of the flows. One of these layers can be followed for about half-a-mile, and varies in thickness from a few inches up to two feet, as a rule, but to the south it becomes much thicker. Its outcrop is shifted a number of times by means of small transverse faults.

Near the junction with the first important ironstone band, zone 2, the lavas become more cleaved and jointed and are sometimes much sheared; the rock at the actual junction is rather crushed and considerably decomposed.

Towards the southern boundary of Logaging there is a narrow band of rhyolite, which swells out as it is followed southwards

[1] Ann. Report for 1906, p. 11.

until it attains a width of a couple of hundred feet. Sometimes it exhibits beautiful flow structure; occasionally it contains spherulites and lithophyses; often it is very fine-grained and has a cherty appearance. It is accompanied by breccias.

The rhyolite appears to be a lenticular intercalation in the diabase, a little below the base of zone 2, and is parallelled by the acid volcanics near Mosita.

The rock composing zone 2 is a finely-banded magnetite jasper rock. About half a mile above the homestead on Logaging the river has cut a narrow notch through this zone, the strata at this point being vertical, and the thickness does not exceed about 100 feet. Further down the river the breadth of the outcrop increases, and the hill on which the beacon called Kging stands owes its width to the repeated folding of these intensely hard ferruginous rocks; this zone is succeeded by a great thickness of green diabases and amygdaloids, accompanied by "pillowy lavas" and breccias (zone 3), and these in turn by a prominent belt of banded red jaspers and cherts, cherts without banding, and banded magnetite-jasper rocks. The jaspers are as a rule confined to the western side of the zone, but there is great variation, for some of the pale cherts pass into brilliant red jaspers along the strike. All these hard rocks are more or less faulted or brecciated, and the space between the blocks is filled with greyish chert.

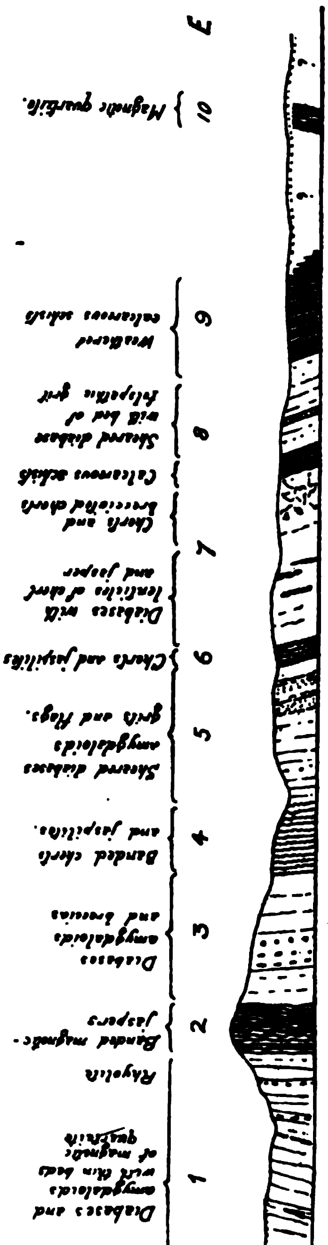

FIG. 1.—Generalized section across the Kraaipan formation from the exposures along the Setlagoli River between Logaging and King's Mill. Distance across the strike of beds about two miles.

Following zone 4, and best seen on Martin's Bush, is another broad belt of volcanic rocks, green in colour and often highly sheared. Peculiar lenticular inclusions of yellow and brown weathering crystalline limestone are probably metamorphosed vein material. These are followed by dark green gritty rocks, some of which appear to be tuffs, and by soft greenish sandstones and flags, which weather with a purplish tint. They are succeeded by cherts and jaspers, very like those of zone 4, but undoubtedly on a higher horizon (zone 6).

The same zone appears further up across a bend in the river, on Kingsmill, at the junction with the Mosita River. It is followed by diabase and amygdaloid, containing narrow bands and lenticles of chert and brilliant red jasper. Next come colourless to greenish grey banded cherts and masses of cherty brecciated rock with fragments of vein-quartz, probably much shattered quartz veins, followed by greyish cherts. Succeeding them is a considerable thickness of rocks, which are very probably calcareous schists, for they are deeply weathered and produce much tufaceous limestone, and leave a network containing green and yellow brown ochreous earthy material.

On the opposite bank of the river, and apparently a little higher up in the succession, we find sheared greenish diabases, between which is intercalated a bed of felspathic grit, about 15 feet in thickness. This grit, or arkose as it is almost entitled to be called, yields most conclusive evidence to the conditions under which rocks of the Kraaipan formation have been deposited. The thin section (1689) shows under the microscope little fragments of quartz, sometimes polarising as a mosaic, and usually showing dusty inclusions; orthoclase, full of tiny flakes of some micaceous mineral, is abundant; plagioclase is present in small fragments. The rock contains fragments of chert, jasper, grit, cherty limestone, rhyolite, and possibly diabase.

It is probable that while this layer was being formed, the lower beds of the Kraaipan formation were undergoing denudation; the abundance of quartz and felspar obviously suggests their derivation from the granite.

The beds immediately succeeding the diabase overlying this grit are not seen, but further up the river are thin-bedded brownish weathering schists, probably of a calcareous nature. After this there is a gap for several hundred yards, and then a band of magnetic quartzites dipping to the west at a high angle crosses the bed of the river.

No further outcrops are seen along the Setlagoli for some distance, and then on Steil Hoogte muscovite-granite makes its appearance. The width of the belt occupied by the Kraaipan formation, where it is cut through by the Setlagoli River, cannot be less than two miles, which will give at least 10,000 feet for the thickness of the series, of which more than one-half is of volcanic origin. As there is not sufficient space between the highest beds and the granite on Steil Hoogte for the different

zones to occur in reverse order, it is probable that the eastern boundary of the belt will be a fault.

On following the belt southwards up the Mosita valley, good sections are found on the farm Blikplaats, where the river has cut its channel along the belt. The diabases of zone 1 are exposed around the homestead, and again in the bed of the river; here also they include thin layers of magnetic quartzite. The magnetite-jasper rock of zone 2 is a little more quartzose than on Logaging, and in a similar manner crosses the valley like a wall. The trigonometrical station is situated on a hill formed by the repeated folding of this stratum.

The third zone can be traced for a considerable distance northwards down the river, but is buried beneath sand to the south, on Moshesh. Zone 4 (cherts and jaspers) is present on the right bank of the river, and extends into Moshesh, where it is much folded. Its character has been previously described.[1] The higher zones are either absent or concealed by red sand.

On Moshesh the granite was proved west of the belt in a well in the bed of the river, but the lowest zone of diabase is not exposed between the river and the ironstones of zone 2.

On the farms Hope and Faith certain volcanic rocks, which were stated in the Report for 1905 to probably belong to the Ventersdorp series, were found to be actually the lowest portion of zone 1. The structure is apparently a synclinal one, parallel in direction to the main belt lying to the east, and the rocks crop out more or less on the left-hand side of the valley, the boundaries being shifted several times by cross-faults.

At the base comes about 150 feet of rhyolite, very hard and with scarcely any visible bedding planes; this is followed by several hundred feet of greenish blue diabase, with amygdaloid structure only feebly developed. The junction between the coarse-grained granite and the rhyolite can be traced for several miles along the western side of the syncline, and the two rocks appear to be almost welded together. It seems that the rhyolite has been poured over a somewhat jagged though not extremely uneven surface of hard granite. Beds of magnetic quartzite appear on different horizons, both in the rhyolite and diabase; they are mostly very thin and rather irregular, and cannot as a rule be followed for any considerable distance.

The lowest one of these beds is found to become more persistent to the south, and on the Mosita Native Reserve it swells out and forms a narrow belt, flanked on either side by granite. It consists of magnetic quartzites and cherts, together with a small amount of diabase, and appears to be a synclinal infold in the granite. The contact with the latter is seen on the south-west side, and it is noteworthy that although there are some white quartz veins in the granite, these are absent in the Kraai-

[1] Ann. Rept. for 1905, p. 225.

pan series, while in one instance the basal layer of magnetic quartzite abuts against a quartz reef. At no point is there any indication that the granite is intrusive.

The exposures of the main belt on the eastern side of Faith and the Mosita Reserve consist of detached ridges of magnetic quartzites, jaspers, and cherts; probably the intervening sand-covered areas between the parallel ridges indicate the existence below ground of the various volcanic zones,[1] but it is not until the northern boundary of the farm Blaauw Krans is reached that the base of the formation is exposed.

The granite is highly sheared here, and is followed by schistose rocks containing blebs of quartz, proving under the microscope to be rhyolites crushed and silicified. These volcanics are succeeded by hard greenish diabasic rocks, and these in turn by a thick bed of magnetic quartzite (zone 2). The volcanics are apparently not more than 300 feet thick here.

A couple of miles further to the south these volcanics make their last appearance, and this zone either dies out in that direction or else is cut out by a strike fault, for the volcanic rocks are absent at Gemsbok Pan.[2]

The western belt dies out just beyond the trigonometrical station Kging on the farm Harriet's Berg, but about six miles further north, on the Molopo, at Kwedi, that river has cut its channel for half a mile through a series of magnetic quartzites and cherts with some light coloured schistose rocks. The beds are somewhat contorted, the general dip being to the east at a high angle.

The Logaging section explains the succession at Pitsani, and renders it clear that the volcanics at the latter locality, believed to belong to the Ventersdorp series, are really a portion of the Kraaipan formation. The diabases, "pillowy lavas," and breccias at the Stad are the basal beds of the formation, as they rest on gneissic granite, and they can be matched with similar volcanics at Logaging. About 1,000 yards west of the Stad are alternations of diabases with magnetic quartzite, ferruginous limestone, magnetic and cherty limestone, cherts, etc., dipping vertically. The diabases are usually more or less sheared, and are sometimes quite schistose.

The ridge through which the river has cut its gorge is formed of massive magnetic quartzites, which probably correspond to one or other of zones 2 and 4, or else to both of them.

Below the poort are again alternations of diabase and magnetic quartzite and chert, and still further west a great development of greenish grits, slates, sheared diabases, and hornblendic schists, with occasional bands of impure chloritic limestone, traversed by quartz veins.

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[1] Since this belt was examined a number of prospecting pits have proved the existence of sheared rhyolite, phyllite, and magnetic quartzite beneath these sand-covered areas.

[2] Ann. Rept. Geol. Commn. for 1905, p. 224.

The rocks are only seen along the bank of the river for about a mile; further on, the strata are hidden by tufa and gravels, and the only outcrops noticed were those of a few quartz reefs.

Both at Logaging and at Pitsani the succession reckoned from the granite is similar, and in each case the general dip of the strata is towards the east at high angles. It is therefore very probable that the entire succession at Pitsani is an inverted one. The volcanics noticed along the Molopo above Pitsani, and again on the Piring Spruit, will in consequence of these investigations now have to be included in the Kraaipan formation.

At Kraaipan, Wodehouse Kraal, and Madibi, prospecting shafts put down recently have in certain cases shown that no small proportion of the formation must consist of volcanic material. Usually these rocks are diabases, sometimes they are more basic rocks, while some are apparently tuffs. Owing to the great amount of dynamic metamorphism to which the beds have been subjected in these localities, the volcanics have been sheared and recrystallised, so that they are now represented by hornblende schist, chlorite-biotite schist, chlorite-schist, etc.

West of Mosita a small outlier of magnetic rocks was found on Beaulieu, one of the recently-surveyed farms of the First Railway Grant north of Genesa. The patch is only a few hundred yards long, and consists of contorted magnetite-quartz and magnetite-actinolite rocks, with variable dips and with a general north-north-easterly strike. The formation round about is hidden by sand and ironstone gravel, but gneissic granite was proved in boreholes not far distant from this outcrop. This outlier is of great interest, because it shows the former widespread distribution of the rocks of the Kraaipan formation; it also forms a link between the exposures at Gemsbok Pan and Zoete Inval, and those recorded by Mr. Rogers from Kameel Rand[1] not far from Motiton.

Petrological Description.

A. Rhyolites. These are cream-coloured, fine-grained rocks, without any prominent ferro-magnesian constituents. The quartz crystals are seldom much corroded, and they almost always show marked undulating extinction, indicating the great strains which the rocks have undergone.

One section (1418) of a rhyolite collected not far from the junction with the granite on Faith (Mosita) shows abundant crystals of quartz and a large crystal of micropegmatite. The groundmass is full of small whisps of white mica, and a small amount of biotite which is mostly altered to chlorite.

Another specimen (1692) from the same farm contains large

[1] Ann. Rept. for 1906, p. 12.

Carlsbad twins of orthoclase, generally more corroded than the crystals of quartz. The groundmass consists of interlocking areas of quartz and felspar, tiny ragged flakes of biotite altering to chlorite, and numerous little rhombohedra originally of iron carbonates, but which are generally altered to iron oxide.

In slide 1686 from Logaging the quartz crystals show a well-marked zoning, and are sometimes cracked across and faulted.

B. Diabases, etc. These rocks are dark green in colour, fine grained, and usually more or less sheared. Amygdaloidal varieties are not very abundant, and when present, the vesicles are seldom large. In thin section under the microscope it is difficult to make out the original nature of the rocks, even in the case of the unsheared varieties. Usually the felspar is still recognisable, as in section 1681, from zone 1 at Logaging; in this slide it occurs as narrow laths and elongated crystals. The original ferro-magnesian mineral has invariably been altered; in the section just mentioned, it is represented by large chloritic pseudomorphs. In most instances augite appears to have been present originally, but is now represented by pale greenish yellow hornblende (uralite), accompanied by a little calcite, epidote, and chlorite.

This is well seen in section 1682, from the same zone at Logaging. The rock shows a good ophitic structure, but the pyroxene is replaced by uralite, and the felspar is quite cloudy and altered. Ilmenite is still present.

In 1691, from zone 1 on Faith, the change has proceeded a little further; the augite is replaced by uralite, and the felspar has given rise to an aggregate of epidote, zoisite, uralite, quartz, and also a little clear secondary felspar.

A more advanced stage of metamorphism is seen in a diabase (1673) from near the base of the formation at Kraaipan station. The large areas of uralite are set in a groundmass of clear felspar, crowded with little inclusions of epidote, zoisite, uralite, etc. The ilmenite is altered to leucoxene and sphene, while the uralite shows a partial conversion into chlorite. The rock is traversed by planes of shear, and there is a tendency to orientation among the uralites and to the arrangement of the felspar in bands. The areas of sphene are drawn out and elongated. Section 1674 of a schistose rock taken from a well at the store at Kraaipan shows elongated and well-formed prisms of indefinitely terminated blue-green hornblende, set in a colourless water-clear aggregate of quartz, plagioclase, and possibly also albite, in which are embedded needles of actinolite and granules of epidote and iron ores.

The rock has been completely recrystallised, and can be called a ***hornblende-schist.***

Heavy serpentine rocks were obtained from a prospecting shaft two miles east of Kraaipan, but there is nothing to indicate whether they represent lavas or are intrusions.

The chlorite-schists are probably more closely related to the phyllites than to the diabases, and may possibly represent metamorphosed sediments or fine-grained tuffs. A specimen (1670) from the main shaft at Madibi is a well-foliated rock, showing small interlocking areas of quartz, having inclusions of rutile and sometimes of iron ore. Chlorite is abundant in small, almost idiomorphic, plates. Rhombohedra of calcite or dolomite penetrate the quartz, and are aggregated round the iron ores and sphene, or else are arranged in layers. Magnetite and sphene are abundant, the latter being more or less altered to leucoxene.

C. Banded Ironstones and Jaspilites. The thin layers of magnetite-quartz rock which occur intercalated between the lavas in zone I are indistinguishable from the thicker beds in hand specimen, but under the microscope are found to retain traces of their original structure.

A thin band from Logaging shows (1683) under the microscope a groundmass of quartz, in which are more or less lenticular or irregular areas of iron ores. The quartz areas are remarkably uniform in size, and are polygonal in outline. In the interior of almost each area is a more or less well-defined circular or oval portion, which is crowded with excessively minute particles, probably iron ores; the boundaries of many of the quartz areas are marked out by films of haematite. Probably the dusty portions of the quartz areas represent original grains of quartz now in process of recrystallisation, with the elimination of the ferruginous material. There are also slightly-brownish patches, which under a very high power appear to be grains of felspar in process of silicification. The twinning is nearly obliterated, but the cleavage planes are marked out by rows of inclusions, little colourless rods chiefly, also flakes of haematite. Many of the quartz areas are traversed by parallel rows of these inclusions, the sole indication of the secondary origin of the quartz. The orientation of the inclusions is different in the various grains, and is therefore not due to schistosity.

The rock appears to have been originally a felspathic quartzite, with a certain amount of ferruginous material. In the process of silicification the iron has been concentrated along certain lines, which correspond more or less closely to the bedding planes of the deposit.

The junction of these thin layers of magnetic quartzites with the volcanic rocks is always sharp, and usually it is difficult to obtain a hand specimen exhibiting the junction intact; there appears to be no gradation from the diabase into the magnetite-quartz rock.

At only one place were there no signs of any discontinuity, namely, on Faith, where a thin bed of green ferruginous rock a few inches thick appeared to have the same origin as the diabase in which it occurred. A thin section (1693) shows a rock with rather irregular bedding, composed of quartz, actinolite, and

iron ores. The quartz forms a very fine-textured mosaic, crowded with needles of actinolite. Round the crystals of magnetite and haematite the needles of actinolite are generally collected, and there results a banded rock with streaks of quartz, quartz with actinolite needles, actinolite, and iron ores. This rock has therefore a great resemblance to the magnetite-actinolite-quartz rocks described from near Maribogo.[1]

A specimen (1676) from a shaft two miles east of Kraaipan is a greenish actinolite rock, with layers of brownish quartz, and in section shows crystals of clear actinolite, possessing a pleochroism from pale green to colourless, two finely-developed cleavages, and occasionally good twinning.

Magnetite is present in quantity, and is arranged in bands alternating with the actinolite. Apatite is abundant as inclusions in the amphibole along certain bands. This rock, the bulk of which consists of amphibole, grades into one rich in magnetite (1677), the iron ore occurring in well-formed octahedra. A portion of the iron of the actinolite has separated out in the form of limonite along the cleavage cracks, and the mineral is non-pleochroic.

The mineral here termed actinolite appears to approach very closely to the so-called grünerite of the Lake Superior region, but it differs in several respects from the type mineral grünerite, The density, as determined by a heavy solution, is somewhere about 3.2, and it is probably intermediate in composition between actinolite and grünerite and may possibly be the variety known as cummingtonite, in which some of the iron is replaced by magnesium. The mineral in 1676 is certainly nearer actinolite than grünerite, and possesses a weak pleochroism, a high double refraction, and a well-developed twinning parallel to the orthopinacoid. It is interesting to note that while the amphibole of the Kraaipan ironstones is the ferriferous and magnesian variety actinolite, that of the Griqua Town ironstones is the soda-rich ferriferous variety crocidolite, and each of these is a non-aluminous amphibole.

One of the best illustrations of the development of the actinolite is provided by a specimen from the farm Beaulieu, north-east of Genesa. The section (1706) shows a quartz mosaic, in which the individuals are remarkably uniform in size, and somewhat elongated in the direction of foliation. Between the quartz individuals or penetrating them are small elongated areas of pale actinolite, usually irregular in outline, and never definitely terminated. In certain bands the actinolites become larger, showing cleavage and twinning, and including numerous little areas of quartz and granules of iron ores. The more ferruginous layers show large octahedra of magnetite embedded in quartz

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[1] Ann. Report for 1905, p. 233.

and actinolite accompanied by haematite, probably of secondary origin. Apatite is abundant in the form of minute prisms.

The banded ferruginous cherts are very much like those of the Griqua Town series, showing layers of granular quartz and of magnetite and haematite, the rocks being completely recrystallised. The layers are often broken by small faults, which are occupied by narrow veins of quartz.

The banded jaspilites from Moshesh are interesting rocks, for they show two and sometimes three different series of quartz veins, the earlier of which have experienced earth movement, by which the quartz has been granulitized. The iron is in an extremely finely-divided condition, and is probably mostly in the form of minute flakes of haematite; often they are so crowded together that the base of the rock cannot be resolved. The haematite may be accompanied by magnetite. A section (1695) from Moshesh shows numerous minute rhomboidal areas, which are more abundant along certain layers in the rock. Usually these rhombohedral spaces are occupied by quartz in minute areas, grains of iron ore, some dusty matter, and tiny granules of a pale yellowish indeterminate mineral, and they are set in a groundmass of chert and iron ores. Sometimes the rhombohedra show an interior of chert and dusty material, a narrow zone of almost opaque iron ore, and finally an exterior shell of clear chert. It can hardly be doubted that these areas represent rhombohedra of carbonates of iron and lime, and that the rock owes its present character to the silicification of a chert containing rhombohedra of iron-bearing carbonates, which were arranged along the bedding planes. Such rocks are represented by certain cherts in the Campbell Rand and Black Reef series, and seem to have arisen from the alteration of extremely fine-grained siliceous sediments, containing small amounts of carbonates of lime and iron.

It is interesting to note that some of the banded ironstones of the Griqua Town series show similar rhomboidal areas of chert and iron ore, usually bordered by limonite and set in a groundmass of colourless chert.

The Origin of the Banded Ironstones and Jaspilites.

The evidence collected so far points to these ferruginous and cherty rocks as deposits of sedimentary origin, interstratified with the volcanics. With the one or two exceptions that have been referred to already, these beds are sharply defined from the volcanics with which they are intercalated; the exceptions described very probably indicate the mingling of volcanic detritus with the sediment then being deposited.

The remarkable regularity of most of the ferruginous and cherty zones, recognisable often over wide areas, indicates a state of even deposition that did not obtain in the case of the

volcanics. This regularity is exhibited to a remarkable degree both in hand specimens and in thin sections under the microscope, and there cannot be the slightest hesitation in concluding that this banding, as indicated by the layers of different mineral composition, represents an original structure due to variation in the nature and composition of the sediment deposited, and therefore that they are planes of bedding.

The shearing which these rocks have subsequently undergone has produced intense puckering and contortion of the laminae, more especially in the case of the magnetite-quartz rocks, but the jaspilites seem to have been less plastic and more brittle, and the effect of earth-movements has been to brecciate these rocks to a wonderful degree, without however obliterating their original structures.. The shearing has sometimes been so intense that strain-slip cleavage (ausweichungs-clivage) has been produced in certain of the layers, but in no case is there any uncertainty regarding the original lamination. (See also Ann. Rept. for 1905, p. 229.)

The origin of the cherty rocks and jaspilites is a problem which seems to offer less difficulties in the way of a satisfactory solution than that of the more magnetic varieties.

From what has been said on pp. 135-7, it seems most probable that these rocks were derived from fine-grained sediments, highly siliceous in character, but carrying small amounts of carbonates, principally those of calcium and iron, probably that of magnesium also. In one of the jaspilite sections (1694) there are small oval bodies, composed chiefly of chert and haematite, that have a considerable resemblance to the altered "greenalite" granules of some of the cherts of the Mesabi area, Lake Superior.[1] They are, however, not abundant in the slide, and may very probably be of secondary origin. In the metamorphism of the sediments the calcareous matter has separated out in the form of minute rhombohedra, and the abundance of rhomboidal areas along certain lines of bedding indicates their formation along bands richer in carbonate than the rest of the rock. A further change has resulted in the oxidation and removal of the calcareous material, and the rhombohedral spaces are thus occupied by chert, haematite, and limonite. The minute specks of haematite diffused through the cherty groundmass may in part have been derived from the iron leached out from these minute rhombohedral spaces, but some of it has apparently been introduced subsequently. It has already been remarked that the jaspilities are much fractured, and that one set of these fractures is considerably earlier than the others. The process involved in the leaching out of the iron and its subsequent dissemination through the groundmass is evidently intimately connected with the solution of the silica and the infilling of these fractures with quartz.

[1] United States Geological Survey. Monograph 43. 1903.

Thus certain small areas bounded by minute veins of quartz are frequently almost opaque from the abundance of granules and flakes of haematite, while in those adjoining the pigmentation is much less intense; at the same time, the bedding is still recognisable.

The mineral transference appears therefore to have been most active at the period of formation of the first series of veins. On a large scale, this variation is found in the field, for beds of brilliant red jasper behave most irregularly along the strike, and may be replaced within a short distance by nearly colourless banded chert. This variation does not imply any marked change in chemical composition of the rock, for the actual amount of haematite in the bright red jaspers is as a rule very small indeed.

The problem of the origin of the magnetite-quartz and magnetite-actinolite rocks is a much more obscure and difficult one.

Much as the Kraaipan ironstones resemble the lithologically similar iron ores of Lake Superior or of Scandinavia, they nevertheless do not show sufficient evidence of having been derived in exactly the same way as the ironstones in either one or other of these two regions. In the case of the American ores, it has been shown[1] that the magnetite and haematite have been formed by water circulating through ferruginous cherts and carbonate rocks, with consequent recrystallisation and metamorphism of the material so altered. The ores consist of more or less lenticular, and sometimes irregular bodies included in masses of chert and limestone, and each lenticle of iron ore if followed downwards will probably ultimately be replaced by one or other of these two rocks. The change has evidently taken place in the surface zone of alteration.

The Scandinavian ores[2] show the same variation in iron-content, and appear to be all connected more or less closely with masses of igneous rock of various types, the alteration having taken place in the zone of anamorphism.

In the Kraaipan ironstones the original bedding is everywhere recognisable, and so far as can be judged, there seems to be no reason to doubt that each zone will maintain its ferruginous character if followed downwards below the surface. This is not capable of direct proof, but the following can be put forward in support of such an assumption:—Pebbles of banded ironstone and jaspilite are found in the conglomerate at the base of the Pniel series east of Mosita, showing that the rocks of the Kraaipan series exposed at the time of the formation of the conglomerate possessed the same lithological characters as in the outcrops that are to-day visible. Bearing in mind the

[1] C. K. Leith: Bi-monthly Bulletin of the American Institute of Mining Engineers, No. 3, 1905.

[2] H. Sjögren: Bi-monthly Bulletin of the American Institute of Mining Engineers, No, 18, 1907.

great amount of denudation that the outcrops of the Kraaipan formation have undergone since the removal of the overlying Pniel conglomerate we have a strong argument against believing the metamorphism of the ironstones to be merely a superficial phenomenon. The changes which the rocks experienced must therefore in all probability have affected each layer throughout its original extent in a regular though not necessarily uniform manner, and these changes had been completed at a period anterior to the formation of the rocks of the Ventersdorp system.

The only alteration comparable with that which produced the Lake Superior ores is the alteration of some of the magnetite to haematite, a change which has taken place in the surface zone. At Madibi a banded ironstone from the 250 foot level is a black and white magnetite-quartz rock devoid of haematite, while at the outcrop all the ironstones have red and brown tints. From this it must be concluded that the haematite is an alteration product of the magnetic iron, a conclusion strengthened by the fact that wherever the ironstones have been much brecciated the proportion of haematite is high. There has evidently been a circulation of water along the lines of fracture, and some of the magnetite has been oxidised to haematite. The quartz may even in certain cases have been replaced by haematite with the production of almost pure iron ores.[1]

This concentration of the iron is not so common, however, in the Kraaipan formation as in the Griqua Town series, where the process has taken place on a huge scale with the production of the Blink Klip (haematitic) breccias.[2]

Again, it cannot be assumed that the Kraaipan ironstones have been derived from impure ferruginous limestones and dolomites by a process of solution and recrystallisation. At Pitsani and again at Kraaipan there are intercalated between the magnetic quartzites layers of ferruginous limestone, into which the magnetic rocks grade almost imperceptibly. As the formation maintains a lithological uniformity over great distances round about, it seems hardly possible that such small layers of carbonate rock should have completely escaped alteration while the rest of the formation became wholly recrystallized and converted through metamorphism into schistose rocks devoid of carbonates but containing magnetite. Again, in the sheared diabases are veins and lenticles of ferruginous and chloritic limestone, while between banded ironstones at Madibi occur beds of calcareous schists with small crystals of magnetite.

It seems curious, too, that supposing the recrystallization to have been caused by the extensive circulation of waters underground, no alteration should have been produced either in these carbonate-bearing rocks or in the volcanics with which the ironstones are interbedded. The diabases show alterations of

[1] Ann. Rept. for 1905, p. 233.

[2] Ann. Rept. for 1906, p. 35-39. Trans. Geol. Soc., S.A., Vol. IX., p. 6, 1906,

the mineral constituents, it is true, but these are more of the nature of paramorphic changes, and the lavas never exhibit the extensive silicification which has often affected the volcanics of the much younger Ventersdorp system. Neither in the diabases nor in the granite have there been found any veins filled with quartz and iron ores such as would be expected had the metamorphism been accompanied by the extensive transference of mineral matter through the agency of solutions.

Taking all this evidence into consideration, it appears that the mineralogical changes that took place in the formation of the magnetic rocks have been more of the nature of a rearrangement of the existing mineral constituents rather than a molecular replacement of certain substances by others brought in by solutions, and therefore that the magnetite-quartz rocks were very likely siliceous ferruginous sediments to start with. In this connection the evidence yielded by section 1,683 described above is of immense value.

The hypothesis that the magnetite may have arisen through the oxidation of pyrites and that the sediments were originally pyritic in character is a very attractive one, but is attended with difficulties. It first of all requires a reduction of the iron to the sulphide condition, and subsequently its re-oxidation, the latter process being one which is unlikely to have taken place in the zone of anamorphism. The objections based upon the absence of veins of iron ore in the diabase apply in this case still more forcibly, for it is very improbable that the volcanics should have failed to have become impregnated with pyrites, whereas the actual proportion of iron ores in them is always low.

It may be that these deposits were of the nature of bog-iron ore as suggested by Weidman[1] for the origin of certain haematites in Wisconsin; on the other hand, the intercalation of the magnetic rocks, jaspilites, etc., between immense thicknesses of volcanic material is not without significance, and it seems more probable that they were of the nature of chemically deposited sediments. It is interesting at this point to notice that brilliant red jaspers identical with those of the Kraaipan formation have been found interbedded in the volcanics of the Ongeluk division of the Griqua Town series[2] in Hay.

At the same time it must be remembered that the lower zones of the formation were experiencing denudation, while the upper ones were in process of deposition, so that a great amount of sediment composed of small particles of ferro-magnesian silicates and grains of iron ores would have been produced by the weathering and disintegration of the volcanic material, while sedimentation would also have been aided by the incorporation of volcanic ash.

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[1] Wisconsin Geological and Natural History Survey. Bull. No. XIII. "The Baraboo Iron-bearing District." 1904.

[2] Ann. Rept. Geol. Comm. for 1906, p. 44-5.

It is important to note that the source of the iron in the Iron-bearing formations of Lake Superior has been largely ascribed to sediment derived from the denudation of the more ancient basic volcanic rocks of that region.

The magnetite-quartz rocks evidently represent the more siliceous sediments, the magnetite-actinolite rocks, those containing a considerable amount of magnesia and possibly also a little lime. Through metamorphism and earth movement they were converted into crystalline schists with crumpled lamination planes. The cherts and jaspilites having been more brittle show less contortion and more fracturing. The diabases and tuffs show the effects of shearing and metamorphism, and are in places converted into hornblende and chlorite schists.

The solutions which circulated along the lines of fracture dissolved and redeposited silica, and oxidised the magnetite to haematite. At a late stage tourmaline, pyrites, and pyrrhotine were introduced, together with a small amount of copper and gold. A section of the country rock (1,672) of the auriferous lode at the Madibi Mine shows that while the octahedra of magnetite are much fractured the crystals of pyrites are unaffected, and that occasionally the latter mineral has crystallised in the cracks developed in the iron ores.

V. The Transvaal System.

The Black Reef, Campbell Rand, and Griqua Town series are found north of Morokwen, making it evident that these rocks are the continuation of the formations seen near Kuruman though hidden for the most part between these places by superficial deposits. The belt extends east-north-east towards the extreme north-west corner of Mafeking, where the strata are again buried beneath red sand. The dip is to the north-north-west at low angles.

It seems verv probable that the rocks of this system continue beneath the superficial deposits into the Bechuanaland Protectorate. This is very interesting because the rocks of the Transvaal system form in the Marico District[1] a huge syncline which extends westwards into the Protectorate. Little is known about this territory geologically, but Molyneux[2] has given reasons for believing that the synclinal structure continues westwards. Taken in conjunction with the reported occurrences of dolomite limestone over a large area west of Kanya it seems very probable that the Morokwen outcrops constitute a portion

[1] Hatch and Corstorphine. Geology of South Africa, p. 166.
[2] Molyneux. Proc. Rhodesia Sci. Assocn., vol. vi., p. 76, 1906.

of the southern limits of this syncline which is opening out again towards the west.

The geological structure of the divisions of Mafeking and Vryburg is thus revealed as a very flat dome away from which the rocks of the Transvaal system dip at gentle angles. Between Lichtenburg and Vryburg denudation has removed the Black Reef beds, and thus destroyed the regularity of the structure. The outliers of the Black Reef series at Zoete Inval and Blink Klip indicate that the arching up of the dome was not so very considerable.

A. The Black Reef Series.

A few miles to the north and north-west of Morokwen the rocks belonging to this series crop out at the summit of a sandy ridge of gentle slope. The formation is not at all well exposed, and as the beds dip at very low angles towards the north-west it is difficult to be sure of its exact thickness. Probably it is not more than 30 feet thick at any point; this is much less than at Vryburg or Motiton, but is almost the same as on the Transvaal border east of Mafeking.

The Black Reef rests directly on the granite without the intervention of the volcanics of the Pniel series; the contact is well seen in some prospecting trenches about four miles due north of Morokwen, just within the Native Reserve. In one trench the granite is found traversed by a wide quartz vein, and the overlying Black Reef quartzite is crowded with more or less rounded fragments of quartz and granite, while the matrix is composed of granitic debris. These conglomerates are only present at the base of the formation, and are succeeded by gritty and felspathic quartzites; some soft shaly beds are also present.

A short distance to the north-east, where the formation is exposed in the extreme northern angle of the farm Highlands, the rock is again a hard, light coloured quartzite passing into an arkose and containing pebbles of quartz and granite. On the south side of the farm Kolokolani there is a peculiar exposure as an inlier surrounded by Campbell Rand dolomitic limestones. The pan in which the rocks are exposed is a little over a hundred yards across, and has its floor composed of grey gneissic granite. On the east side the junction of the Black Reef with the latter is well seen. The rock is a dark grey, felspathic, gritty quartzite, adhering firmly to the slightly irregular surface of the granite. The basal layer is in places an arkose, and contains light coloured masses of granitic material, apparently pebbles of granite that were already partially weathered at the time of their entombment in the sediment.

For about twenty miles from this point the formations are buried beneath red sand, until in the Genesa laagte, on the boundary line between the farms Fouché's Rust and Venter's Rust, the Black Reef is again exposed with a dip of about 3° to

the north below the dolomitic limestone. The formation upon which it rests is not seen here, but gneissic granite was proved in a well about five miles to the south.

The strike of the Black Reef series between Morokwen and Fouche's Rust is about east-north-east; this would, if extended, make the formation cross the Molopo in the neighbourhood of Mabul. None of the wells in the river bed thereabout are deep enough to lay bare the underlying formation.

B. The Campbell Rand Series.

Rocks belonging to this formation cover an area of several hundred square miles north-west of Morokwen, and constituting a belt from 15 to 20 miles wide, succeeded to the north-west by the Griqua Town beds. Small inliers are found amid the red sand east of the main area, *e.g.*, on Mositlani Pan and Quarree Fontein, and in the Genesa laagte on Fouché's Rust.

Due north of Morokwen the dolomitic limestones support a dense growth of hakdoorn (*Acacia detinens*), and their junction with the Black Reef is delimited almost exactly by these thorn trees. This belt of hakdoorn is an extraordinary feature; where the dolomitic limestone is absent or else deeply buried beneath sand, *e.g.*, to the north-east and south-east, its place is taken by other species of acacias. To the south-west it flourishes on the hard calcareous tufa which overlies the dolomite.

The rocks forming the Campbell Rand series are the usual dolomites, limestones, cherts, and occasionally shales that are so characteristic of this formation in Vryburg, Griqualand West, and in the Transvaal. The lower half of the formation is practically free from layers of chert; it is almost entirely composed of limestone and dolomite with thin shaly layers, the last named rather rarely exposed.

A most remarkable feature about the area occupied by these lower beds is the presence of an extraordinary number of the peculiar ridges known as *aars*; reference to these, as occurring in the Kuruman district, has already been made by Mr. Rogers.[1]

These aars form well-defined ridges rising from a few feet up to ten or even fifteen feet above the surrounding flat country; they extend usually in nearly perfectly straight lines.

Sometimes dolomitic limestone is exposed on the ridges, but more commonly the crests are formed by calcareous tufa: invariably they support a dense growth of trees and shrubs. As the belt is followed into an area where the strata become covered up by the red sand, the height of the aars diminishes, they become low, sandy ridges, and ultimately the aar is marked by a regular line of trees only.

The commonest trend of the aars is about north-east, or

[1] Ann. Rept. Geol. Comm. for 1906, p. 64-6.

parallel to the strike of the formation in this locality; sometimes they are so numerous as to be only from 100 to 200 yards apart. They are crossed by other aars, the direction of which is more variable, but which generally lie between north 15° west, and north 30° west. By the intersection of these ridges, hollows are produced, and thus the area is characterised by innumerable small pans with rocky floors; these hold water for a short period after rain.

An excellent view of these aars can be obtained from the summit of the ridge known as Koodoo's Kop, due north of Morokwen. The country becomes more open and grassy, while across it run in various directions long lines of trees forming a geometrical network and appearing as if laid out artificially.

The formation and general direction of these aars is intimately connected with the two main sets of joints in the dolomite limestone, and in the majority of instances they are apparently due to the enlargement through solution of these joints, by which a soil has been produced, thus stimulating the growth of vegetation. In a few instances hard beds have been instrumental in their determination. In other cases their position may have been determined by gentle foldings, for the strata dip away on either side. In only a few examples have the aars resulted from intrusions of igneous rock.

The presence of the network of aars in the sand-covered area to the north-east and south-west may safely be considered evidence of the underground extension in these directions of the Campbell Rand formation.

The upper portion of the Campbell Rand series is characterised by the presence of thick beds of banded or massive cherts, more rarely of calcareous quartzite. The cherts form low ridges, the most prominent being that known as Koodoo's Kop on the north-east boundary of the Morokwen Native Reserve. It rises about 200 feet, and is formed of dolomitic limestones capped by banded and massive white and grey cherts, cherty quartzites, and vein quartz with very little limestone. The outcrop of this prominent stratum can be followed north-eastwards past Nokani Pan to Quarree Fontein, while to the south-west it forms a belt several miles wide crossing the Native Reserve. The dip is at a low angle to the north-west.

Alternations of chert and dolomitic limestone are numerous on Armidale and Tlaping, the beds being near the upper limit of the formation. On each of these farms there is an interesting pan, the floor being formed of nearly horizontal beds of dolomite on which are numerous rock-engravings executed by the aborigines of the district.

The Griqua Town beds form the high ground to the north-west, and though the actual junction with the Campbell Rand series is not very well exposed, the transition appears to be quite abrupt. The best section is seen at the end of a narrow ridge

on Tlaping, practically on the boundary of the latter with the Setaben Crown Reserve.

The Griqua Town beds form a sharp syncline, with dips frequently exceeding 60°. The uppermost stratum of the underlying formation is a massive grey chert more or less banded; it becomes dark brownish-black, and contains a few ferruginous layers higher up, and this is succeeded by the typical red and black banded ironstones of the Griqua Town series.

A similar succession is represented at the beacon common to Armidale, Stilton and Kglare, where a little infold of banded ironstones rests on massive chocolate-brown and white chert. The formation along the north side of the Morokwen Native Reserve is traversed by a number of quartz reefs which have been prospected on a small scale without any satisfactory results.

C. The Griqua Town Series.

These beds form a belt with a maximum width of about eight miles north-west of Tlaping, but further to the east the outcrops give rise to a chain of more or less detached hills rising out of the sand and stretching in an east-north-easterly direction almost as far as the Mafeking divisional boundary, a total distance of about forty-five miles. In the opposite direction the ridge breaks off to reappear towards the south-west in the Honing Vley Hills. The area extending westwards to the Molopo is unsurveyed, and very little information is obtainable about it. It appears to be a great tract of flat country covered with thorn bush, and in which the underlying rocks are hidden by calcareous tufa and red sand. Large pans are reported to exist in that direction.

The country extending northwards from these hills of Griqua Town beds to the Molopo is formed of deep red sand, and is covered by extremely dense bush. It slopes gradually to the river. A short description of the physical and geological features of this stretch of monotonous country has been given by Penning.[1]

The strata forming the ridges just referred to belong entirely to the lower division of the Griqua Town series; no outcrops of the Ongeluk volcanics were observed towards the north-west. The strata are as a rule inclined at low angles, generally from 5° to 15°, the dip being usually to the north-north-west. Near Setaben the dips increase in value, and the formation appears to be affected by two sets of folds, one striking north-east and the other north-west very nearly. The strike becomes more easterly as the Mafeking boundary is approached, and in the last exposure in that direction the beds strike practically east and west.

[1] Gold and Diamonds. Chapter V., London, 1901.

The rocks are the usual yellow, brown, and black banded magnetic quartzites, like those described from the Hay and Kuruman districts.[1] They have a great resemblance to some of the banded ironstones of the Kraaipan formation, but are usually yellower in colour and seldom show contorted laminae.

Yellowish brown jaspers are very abundant, red jaspers uncommon; cherty layers and banded ferruginous cherts are very conspicuous, but quartzites are rare. At the south-west corner beacon of the farm Woodborough are a few exposures of reddish weathering sandstone. Thin layers of fibrous crocidolite (asbestos) are not uncommon, *e.g.*, Knysna, Shuenuie, etc., but no attempt has yet been made to work these deposits. The crocidolite is accompanied by its usual oxidation and silicification products.

One of the most conspicuous features in this waterless area is the occurrence after the rainy season of small springs high up on the slopes of these ironstone hills, at points where one would not expect to find anything of this nature.

Their presence is in most cases due to the cementing together with ferric oxide of sand and fragments of banded ironstone lying on the surface of the rock. The breccia thus formed is often many feet in thickness, and water is stored up in hollows and cavities in the deposit. A very good example of this is found on the farm Sweet Water, where a strong supply can be obtained from a reservoir of this sort through a couple of openings not more than two feet in diameter. At the time of my visit the holes had been partly choked up with dead beetles and locusts. The ironstone hills rise out of a sandy grass-covered tract, and in most cases the sand hides all outcrops at the base of the ridges, leaving the rock exposed only towards the summits. At the very eastern end of the chain of ridges there are marked depressions surrounding the hills, and separating them from the flattish tract of sand and bush-covered country both to north and south. These hollows have very probably been produced partly by rain and partly by the wind.

VI. The Superficial Deposits.

The greater portion of this area is covered by superficial deposits, frequently of considerable thickness, and through which the rocks of the harder formations project in the form of isolated knobs and ridges separated from one another by extensive tracts of approximately level country. This peculiar type of scenery *(Inselberg landschaft* of the Germans) is characteristic of desert regions, and particularly of the Kalahari.

The superficial deposits cannot as yet be sub-divided satisfactorily according to their age, although some are of considerable

[1] Ann. Repts. Geol. Comm. for 1905 and 1906.

antiquity, while others are in process of formation to-day. We have in consequence to classify them according to their lithological characters as follows:—

(1) Sand,
(2) Surface quartzites and ferruginous rocks,
(3) Limestones and associated siliceous rocks.

This three-fold sub-division is not distinctive, for there are frequently transitional varieties.

(1) *Sand*. Over this portion of the Colony sand is the predominating superficial deposit. It always supports a growth of long grass and thorn bush, and is never bare; nowhere are there any sand dunes.

The bulk of the sand is a pale reddish variety, composed of more or less rounded grains of quartz coated with a thin film of iron oxide. In the neighbourhood of the ironstones of the Kraaipan and Griqua Town formations the sand is usually redder in colour; over the Eastern Railway Grant in Mafeking the sand has usually a pale yellowish or pinkish tint.

Where the road crosses the Molopo on the farm Nimrod's Vlei there is exposed some soft sandstone light brown in colour, overlain by red sand and probably produced by the cementing of the latter with limonite and carbonate of lime.

In the vicinity of outcrops of granite and gneiss, or wherever these rocks are immediately below the surface, the sand is usually much coarser in character and contains an abundance of felspar in the form of angular fragments.

Although a certain amount of the red sand has very probably been formed through the disintegration of the granite and gneiss of the district, the felspar being gradually removed by weathering, yet the character of the deposit, and its abundance to the north and west, in the Kalahari, point to the latter region as the source of the great bulk of the sand. The prevailing winds blow from the north and north-west, and the direction of movement of the sand, as shown in the neighbourhood of the pans, is quite in accordance with this view.

In the shallow river valleys, and especially in the river beds, the red tint of the sand is absent, and the latter becomes whitish or grey. This bleaching is probably due to the action of organic compounds by which the ferric oxide is first reduced and then carried off in solution. The same process has gone on during the conversion of the red sand into surface quartzite.

At only a few localities has the thickness of this mantle of red sand been proved in the case of the rising ground between one shallow valley and the next. It appears to vary from a few feet up to nearly 30 feet in depth, and overlies as a rule hard undecomposed granite.

Most of the wells have been sunk in the shallow valleys, and the sections show a variable thickness of sand, sandy wash with

occasional pebbles, and sometimes of clay resting upon a more or less decomposed granite, the last named being the water-bearing formation. Wherever the superficial deposits attain any thickness the lower portions of the sand cover has as a rule been converted by the deposition of silica into a more or less compact rock to which the term "surface quartzite," although from its position rather inappropriate, will apply.

(2) *Surface quartzites and ferruginous rocks.* In a few places the sand is firmly cemented together by means of ferric oxide to form a hard dark brown ironstone deposit. This is generally only found where the sand rests upon the Kraaipan formation, *e.g.*, at Logaging, and the source of the iron is therefore obvious.

More commonly the sand grains are bound together with a siliceous cement and a rock of intense hardness may be produced thereby.

Such rocks have been generally termed "*surface quartzites,*" a name which is unfortunately unsuitable for several reasons. The expression "chalcedon-sandstein," used by Passarge, though less objectionable, fails to convey the exact meaning when the siliceous cement is opaline and not chalcedonic silica. It seems a pity that the term "silcrete," proposed by Lamplugh to indicate rocks of this nature, has not been more generally employed.

The surface-quartzites are not all of the same age, and as they usually occur in more or less isolated patches, it is not often that good evidence is found to prove their relative antiquity.

In several of the river valleys exposures of surface-quartzites exist that are presumably of similar age, for in each case they are underlain by peculiar soft red marls.

These quartzites and marls are typically developed along the Molopo, between Pitsani and Mabul, for a distance of a little over thirty miles, but are found as well at Steil Hoogte on the Setlagoli River, at Tlaping, at Vaalpens Spruit, and at the Wegdraai in the Genesa Valley. The distribution of these deposits is indicated in the accompanying map (fig. 2).

About five miles below Pitsani the calcareous tufa on the banks of the river becomes harder and acquires a pink colour. It gradually passes into a whiter somewhat calcareous surface quartzite, weathering into hard jagged masses which make travelling along the river bank somewhat arduous. The deposit forms a terrace rising from 20 to 25 feet above the bed of the Molopo, and its surface is strewn with pebbles of magnetic quartzite, chert, jasper, quartz, chalcedony, and sometimes diabase and quartzite. A short distance away from the river the ground rises and all is hidden beneath red sand.

A little before reaching the Mobelo Spruit the quartzite terrace becomes higher and better developed, so that the river flows in a low gorge varying in width from a few hundred up to about one thousand yards.

The quartzite cliffs extend up the Mobelo and Logogani spruits and down the Molopo, the distance between them continually diminishing until below Makgori the river channel is sometimes less than 100 yards wide, while the banks are often over 40 feet in height. At Kwedi the river banks are formed by an outcrop of banded ironstones, but the quartzites reappear further down and also along the last five miles of the Setlagoli River, and the low cliffs continue as far as Mabul. Below this point the river banks have a gradual slope, and there are no outcrops of any hard material; the wash in the river bed contains small fragments of tufa and quartzite, but away from it there is nothing except red sand.

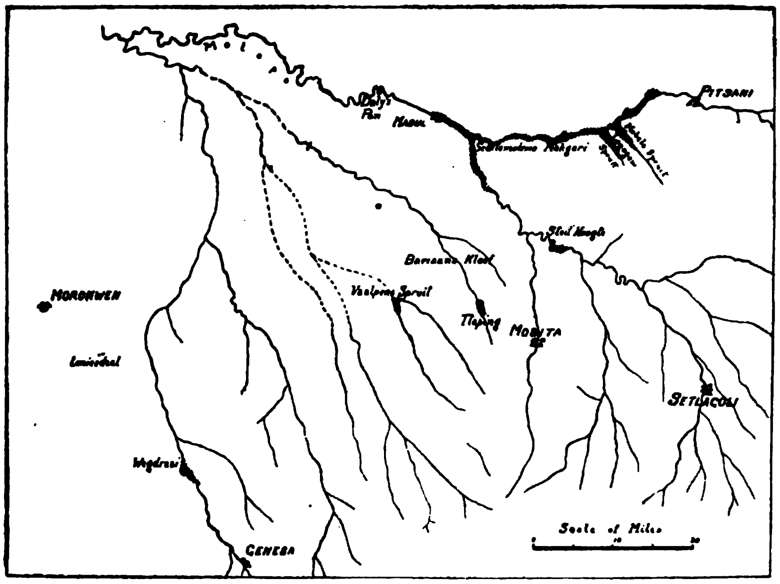

FIG. 2.—Map showing the distribution of the surface-quartzites overlying the red marls.

The quartzites vary in colour from white or grey to pink and sometimes to brown, as on the Logogani Spruit, but the brown tint here is only a surface phenomenon. In places they are fine-grained, in others gritty, and sometimes they are very pebbly, *e.g.*, at Sedilamolomo; in places they are more like sandstones, at others they are greatly silicified, being traversed by veins of opaline silica, or containing druses lined with semi-opal.

A thin section (1,697) from a grey compact variety on the Setlagoli River just above its junction with the Molopo shows under the microscope the following features: The larger grains are usually rounded, while the smaller ones are sub-angular or angular. Quartz is the most abundant constituent; there are

also grains of orthoclase, plagioclase, and microcline felspar, and chert together with granules of epidote and sphene. A few of the grains still retain, or have only partially been deprived of, a coating of limonite, showing that during the formation of the quartzite the mineral grains have had their thin enveloping films of iron oxide partially dissolved away. The cement consists of colourless isotropic silica (opal), but wherever the spaces between the grains have been larger than usual there occur druses lined by or filled with chalcedonic silica.

The surface-quartzites rest upon a deposit, which is but seldom exposed, and then usually only where storm water has excavated little ditches, as for example along footpaths. This formation consists of pink and red marls, and clays hard when dry, but crumbly when moist. They remind one of the red beds of the Stormberg formation, but include no layers of sandstone or limestone. No bedding can be made out, but as they are visible at intervals over a distance of about six miles, from a little to the east of the Mobelo Spruit to a point a little east of Makgori, it is probable that they lie nearly horizontally and conformably beneath the quartzites.

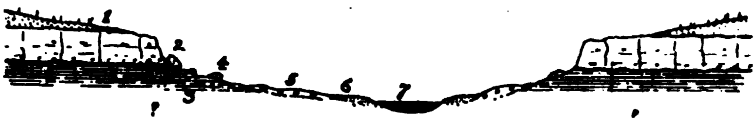

FIG. 3.—Section across the Molopo at a point midway between Pitsani and Makgori. 1, Red sand; 2, surface quartzites; 3, red marls; 4, fallen blocks of surface-quartzite; 5, surface quartzite and breccia, with fragments of 2; 6, light grey and dark grey soil; 7, black alluvium.

The base of the marls is never seen, but in several places they must have a minimum thickness of about 20 feet, and probably much exceed this.

Under the microscope the marl shows abundant minute elongated crystal aggregates of calcite, shaped very much like rice-grains, small fragments of quartz, and some pinkish clayey matter. No diatom remains were noticed in the material.

The general succession along the Molopo is shown in fig. 3. Resting on the sloping surface of marls are blocks of quartzite, which have fallen down from the cliffs. Where these become numerous and repose upon a less inclined surface they have become cemented together with sand and silica, and form a cake of siliceous breccia (5) in which the fragments of the older quartzite are easily recognisable. This younger formation is very well seen at a point a little to the east of the Mobelo Spruit.

The quartzites and marls are present along the Setlagoli River on the farm Steil Hoogte for a short distance. The former are often calcareous and pebbly, the latter are thin and rest directly upon gneissic granite. At Tlaping, west of Mosita,

the granite disappears a short distance down the laagte, and on either side of the valley appear surface quartzites from 20 to 25 feet in thickness, overlain by red sand. The formation extends northwards for several miles, and consists of a hard cavernous rock of varying colour—white, pink, red, etc.—the cavities being lined with opaline silica. There are beautiful druses coated with pale bluish opal, and veins of the same material ramify through the rock.

A small well in the extreme north-western corner of the farm at the foot of the little cliff shows pink and red gritty marls.

A couple of miles further down on Buffels Bosch a shallow pit in the lowest part of the laagte proved the existence of a brownish compact quartzite below whitish river sand, while on Baviaan's Kloof a well passed through alluvium and calcareous tufa into a similar quartzite full of tubular hollows containing soft white sand. These quartzites are undoubtedly much more recent than the siliceous rocks overlying the red marls.

On Vaalpens Spruit a hard siliceous rock like that on Tlaping crops out at the junction of two laagtes. The material is full of cavities and hollows, and superficially resembles to a great degree a vesicular lava. Some portions are white, others pink, and frequently the rock contains pebbles of quartz, banded ironstone, etc.; it is much veined or has its cavities lined with opaline silica. There are no exposures of the marls, but they are in all probability present below the siliceous rocks.

In the Genesa Valley, between Lancewood and the Wegdraai, are similar quartzites reddish in colour and full of peculiar tubular hollows from one to two inches in diameter ramifying through the rock. The well at the Wegdraai passes through tufa, quartzite, and calcareous silicified arkose into granite. An old well two hundred yards to the west proves the existence of red marls below the siliceous deposits.

Distribution of the Surface-quartzites and marls.

The occurrences just described appear only in the valleys where the mantle of sand has been removed or has been prevented from forming. How far these deposits extend beneath the sand and away from the rivers is a matter of uncertainty. It is clear, however, that they do not occur to the south-east of a line drawn from Pitsani through Mosita to Genesa, while boreholes and wells have shown that they are not represented in the area just east and north-east of the Wegdraai.

At Leniesdeel, between the Wegdraai and Morokwen, a well over 60 feet deep has penetrated red sand, calcareous tufa, and sandstone with hard quartzitic portions without proving the

underlying formation. This may possibly be an extension of the quartzites of the Wegdraai.

Again, on the Molopo at Daly's Pan, below Mabul, a well has revealed hard quartzites below sand and tufa in an old cut-off loop of the river.

The quartzites and marls are never found on the high ground, *e.g.*, above about 3,750 feet above sea level, and fall to about 3,550 feet at Mabul. Wherever ridges of hard rock are found, the continuity of the recent formation is broken, *e.g.*, at Kwedi and again between Logaging and Steil Hoogte.

It seems most probable that the marls and quartzites were deposited in a series of valleys, although it is not improbable that their former distribution was much more extensive, for it is clear that in most places the rivers have cut down through the hard quartzites into the soft marls. From the variation in altitude of the different exposures it is unlikely that they are of lacustrine origin however.

The origin of the quartzite will be discussed after a consideration of the calcareous deposits.

(2) *The Calcareous and Associated Rocks.*

The purest variety of calcareous tufa is that which occurs in some of the pans (the *pfannenkalktuff* of Passarge), especially well seen both at Kolokolani and Mositlani Pans north-east of Morokwen.

It forms fairly well defined superimposed layers, varying in thickness from a few inches to a couple of feet, and although snow-white externally possesses a rather drab tint on freshly broken surfaces.

At Mositlani there are at least five of these layers which are nearly horizontal; at Kolokolani the layers dip inwards towards the centre of the pan. The tufa often contains the remains of fresh water mollusca.

The layers are peculiar in possessing numerous narrow perforations extending nearly vertically downwards. They may possibly owe their origin to roots of grasses.

A porous tufa of somewhat similar nature is found in the beds of some of the laagtes between Genesa and Mosita, and sometimes contains shells of mollusca, *e.g.*, at Khudungkwani.

A wide area over the north-western portion of the Morokwen Native Reserve is covered with hard calcareous tufa, somewhat siliceous in places. The deposit is largely due to the presence below ground of the limestones and dolomites of the Campbell Rand series.

At Morokwen, calcareous tufa is found intervening between the granite and the cover of red sand, and is especially well seen at the eastern end of the pan. The drainage from the area round about is directed towards this depression, making its

way along the upper surface of the granite, and thus the formation of tufa beneath the sand is brought about. The water entering the pan is perfectly fresh, while that found in the pan itself is salt.

East of Morokwen, patches of hard tufa project through a thin cover of red sand, but beyond the boundary of the Reserve the latter hides the calcareous deposit. In the laagte on Donegal, a well shows tufa containing veins, layers, and irregular masses of chalcedonic silica varying in tint from black to colourless. At Goed Hoep (Groen Kooi) are wells in calcareous tufa and quartzitic rock with similar streaks of chalcedony, some of which is transparent and either colourless or amber-coloured.

Numerous small implements were obtained from the ground thrown up out of these shallow wells and most of them were made of this chalcedonic silica derived from the veins in the tufa. The amber-coloured material is identical with the stuff from which so many of the implements found at the Victoria Falls have been manufactured.

Origin of the Silcrete Rocks. A complete description of similar rocks from the Kalahari and of their petrographical characters have been given by Passarge[1] and Kalkowsky.[2] Speaking roughly, the rocks are made to fall into two types:—(1) those in which the grains have been cemented together by silica *(eingekieselte gesteine)*, and (2) those in which calcareous material has been replaced by silica *(verkieselte gesteine)*. These two divisions correspond practically to the surface-quartzites and to the silicified tufas respectively. In the one case the solutions have merely deposited silica in the spaces between the sand grains, in the other a certain amount of calcareous matter has been removed by solution simultaneously with the cementation.

It is easy to obtain hand specimens in which both these processes have taken place, and the field evidence shows that the variable nature of the deposits is due to the silicification of materials which range from sand through sandy tufa into a pure calcareous deposit, while not infrequently the rocks are pebbly in character.

Since these silcrete rocks are commonly underlain by soft sands, clays, or marls, and do not rest directly upon the underlying formations, it is clear that the process of silicification does not take place in the materials below but is due to water circulating through the sand and tufa at a depth below the surface where the effect of evaporation is becoming appreciable. The quartzite will thus develop by the gradual induration of the base

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[1] S. Passarge. Die Kalahari. Berlin. 1904.

[2] E. Kalkowsky. Die Verkieselung der Gesteine in der nördlichen Kalahari. Mitt. K. Min.-Geol. Museum. Dresden. 1901.

of its cover of sand in the way which Lamplugh[1] has suggested in discussing the silcrete deposits of the Zambezi Basin.

Many of the quartzites are certainly of considerable antiquity, but the formation of similar rocks may be still going on at the present day.

VII. The Development of the Physical Features of the Area.

Passarge has dealt very fully with the question of the origin of the physical features of the Kalahari, and has brought forward a great number of facts pointing to considerable climatic changes in the past.

Much of his description applies to the area under consideration, but the inferences which I have drawn as regards the development of the area and the climatic variation differ to a certain extent from those of Dr. Passarge.

As already remarked, the area shows that peculiar type of landscape termed "*Inselberg-landschaft*," the origin of which has been fully discussed by Passarge.[2]

There is some uncertainty, however, in this area as to whether the features had not been developed to a considerable degree in Pre-Dwyka times. The chain of hills north-west of Morokwen possesses beautifully smoothed and rounded outlines which recall most strikingly the Griqua Town hills between Griqua Town and Prieska, where the covering of Dwyka tillite has been recently removed. The discovery of Dwyka tillite by Mr. Rogers[3] on the Molopo near Kolingkwani, and by Mr. Molyneux[4] at Mochudi and Palapye, renders it not improbable that a vast area in Bechuanaland has been stripped of its covering of Karroo beds only in very late geological times. Some of the ridges may, therefore, owe their main features to pre-Karroo denudation, the minor sculpturing being due to sub-aerial erosion at a much later period.

That this area has been subjected to active river erosion at a late period in the geological scale is indicated by the existence of banks of coarse gravels[5] between Mafeking and Madibi (K. 14), and again about 12 miles further to the west (K. 11). These fluviatile deposits attain an altitude of 4,203 feet above sea-level at the former locality, and 4,155 feet at the latter, and are, therefore, considerably above the level of the country round about. It is evident that these gravel patches are outliers of a former and more extensive alluvial deposit laid down upon a peneplain that extended from the Transvaal over Mafeking with a gradual westerly slope.

[1] G. W. Lamplugh. Quart. Journ. Geol. Soc., Vol. 63, p. 199, 1907.
[2] S. Passarge. Die Inselberglandschaften in tropischen Afrika. Naturwissenschaftliche Wochenschrift. No. 42. Jena, 1904.
[3] See p. 81.
[4] Molyneux. Proc. Rhodesia Sci. Assocn., Vol. VI., pp. 78-84. 1906.
[5] Ann. Rept. for 1905, p. 255.

The whole of the drainage from this quarter converges towards Pitsani, and passes through a great gorge about half a mile in length and in places nearly 200 feet deep, cut in a ridge of hard magnetic quartzites and cherts. This barrier reaches the altitude of 3,924 feet above sea-level, and must have been instrumental in protecting the area to the east from vigorous erosion. The natural conclusion, therefore, is that the high level gravels were deposited at a period when the Molopo had just commenced to cut its way through this obstacle.

The laying down of the gravels, the cutting of the gorge, and the consequent erosion of the drainage basin must have been accomplished during a period of a higher rainfall than the district now possesses, for at the present time it is only on rare occasions that the Molopo flows for more than a week at a time during the wet summer season. The existence of an early period of heavy rainfall *(pluvialzeit)* seems, therefore, fairly well established.

The red marls, overlain by the surface quartzites and siliceous conglomeratic rocks, commence immediately below the great gorge at Pitsani, their position indicating that they were formed after the cutting through of the barrier. They appear to have been deposited in the ancient valley of the Molopo, and may be regarded as a thick stratum of calcareous mud that has been covered over with sand and gravelly material, the latter having been subsequently indurated. The exact reason for the formation of these deposits is not quite clear. It may be that the material was laid down owing to increase of load from growing tributaries, coupled with the decrease of gradient due to the cutting of the gorge. On the other hand similar quartzites and marls, though of less thickness, occur in valleys having much smaller drainage areas.

It may, therefore, be that the clays, sands and gravels accumulated in the valleys consequent upon a period of diminished rainfall. It must be noted that although the surface-quartzites are frequently conglomeratic, and therefore in great part of fluviatile origin, nevertheless there enter largely into their composition well-worn grains of sand, evidently wind-borne.

The hypothesis of a period of lesser rainfall would at the same time account for the intense silicification of the material and its conversion into quartzite; still, it is not unlikely that the process of induration was again in action at a much later period.

The cutting through of the quartzites until the softer marls, and in some cases the bed rock, became exposed, indicates a renewal of river activity that can only be accounted for by a recurrence of humid conditions. Considering the extremely low gradients (about 3 feet per mile) of the rivers for several hundreds of miles westward, it is clear that this renewed activity cannot be accounted for by an increased slope of the river bed brought about by tilting of the drainage area.

The initiation of this second pluvial period is marked by the occurrence of low-level gravels on the Setlagoli River between Buck Reef and Logaging, on the Molopo just below Pitsani, and by the presence of old loops or "cut-offs" along the river below Mabul. A fine example of a loop now above the level of the river bed is known as Daly's Pan.

Most of the rivers do not seem to have been able to clear out the deposits that filled in their former channels; if ever that were the case they have since been unable to cope with the products of sub-aerial weathering and the quantity of blown sand from the west.

All the larger rivers rise in areas where the hard rocks are frequently exposed, but the small valleys exist entirely in sand-covered country. In the rainy season the rivers flow for a short time, and ultimately the water soaks into the bed of the river and percolates along the sand of the valley bottom. Many of the rivers exist merely in name; for example, the Matlapin Spruit. Although over 40 miles in length, water never flows along its middle reaches. The bed is being obstructed by the accumulation of wind-borne sand and rain-wash, so that in several places the gradient of the valley bottom is reversed.

At the present day the rainfall is high enough to enable vegetation to fix the mantle of red sand, otherwise the rivers would long since have had their channels obliterated. As it is, the disappearance below ground of the surface quartzites on the Molopo, below Mabul, is proof of the invasion of the drainage area by red sand from the Kalahari region of the north-west.

GEOLOGICAL SURVEY OF PORTIONS OF HOPE-TOWN, BRITSTOWN, PRIESKA AND HAY.

By ALEX. L. DU TOIT.

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I.—INTRODUCTION.

The area surveyed forms the continuation of the tract north of the Orange River which was examined last year, and includes a portion of country located between the towns of Prieska, Griqua Town and Hopetown, and extending southwards nearly as far as De Aar.

It thus embraces the greater portion of the Division of Hopetown, portions of Britstown, Prieska and Hay, and small strips of Herbert and Philipstown.

Great difficulty was experienced in the course of the survey owing to the unreliable character of the map of Hopetown, and all topographical details had, therefore, to be determined and inserted in the field. For this reason an attempt was made to utilize the new Military Intelligence Map (on the scale of 1 : 250,000) of the country south of the Orange River. Apart from the many small inaccuracies which were discovered in the course of the survey, the absence of the farm boundaries was a serious defect, and it was found impossible to draw in the geological boundaries with satisfaction.

Two traverses of this area, from Hopetown to Omdraai's Vlei and back, were carried out by Messrs. Rogers and Schwarz, and their observations made on these journeys were incorporated in the Annual Report for 1899.

The extension of the survey into the area done eight years ago, at a time when very little indeed was known about the formations in Northern Cape Colony, has naturally led to certain modifications of the views expressed in the 1899 Report, chiefly in regard to the stratigraphical relations and sub-divisions of the group of volcanics and associated rocks now included in the Ventersdorp system. Attention must also be drawn to a short account of the geology of the T'Kuip Hills by Mr. Rogers.[1]

Physical Characters.

The area can be divided into three fairly distinct regions reckoned from north to south, each one characterised by different physical as well as geological features.

[1] Ann. Rept. for 1905, pp. 149, 150.

The northern region is constituted by the Kaap plateau, with an altitude of about 4,000 feet above sea level, terminating abruptly a little to the north-east of Read's Drift.

To the west are the Griqua Town Hills, or Asbestos Mountains, forming a chain extending northwards from Prieska through Hay, and usually exceeding the altitude of 4,000 feet above sea-level. This country north of the Orange River is often rugged and stony, with a fair amount of vegetation, principally composed of the various smaller species of acacias.

The Orange River flows in a winding gorge, which is nearly always at a considerable depth below the surrounding country; only at the junction with the Vaal River and again near Prieska does its valley widen out to any extent. The gradient of the river is very small, and its altitude near Prieska is only 3,020 feet above sea-level. With such a considerable fall from the Asbestos Mountains to the Orange River there are in consequence a number of tributaries flowing southwards to the latter, the most important being the Sand River which rises a little to the north of Griqua Town.

The central region comprises the northern portion of Hopetown and the eastern portion of Prieska, and is a slightly undulating and very monotonous tract occupied by the Dwyka formation, and covered with little bushes a few feet in height, with here and there a patch of thorn bush or grass land.

In the south we enter typical Karroo country—flats with small Karroo bushes and more or less conical or flat-topped hills of shales capped by sheets of dolerite.

The only river of importance in this region is the Brak River, which, with its various tributaries, takes its rise in the area around Britstown and De Aar.

The northern portion of Hopetown is untraversed by stream courses, there being only very shallow depressions leading either to the Orange or Brak Rivers; commonly the drainage is directed into one or other of the numerous pans, which are a conspicuous feature of this part of the district.

Geology. The geological succession is as follows:—

Recent and Superficial Deposits		Alluvium, sand, calcareous tufa and gravels.
Karroo System	Ecca Series	Flaggy shales and shales with calcareous concretions.
	Dwyka Series	2, Shales with "White Band." 1, Boulder Beds.
Transvaal System	Griqua Town Series (Lower)	Banded ironstones and jaspers.
	Campbell Rand Series	Limestones, dolomites, cherts and shales.
	Black Reef Series	Quartzites and shales.

Vaal River or Ventersdorp System	Pniel Series	2, Diabase, amygdaloid and breccia. 1, Quartzites.
	Kuip Series	Diabase, amygdaloid, arkose, chert, and limestone.
	Zoetlief Series	2, Rhyolites and felsites. 1, Grits and conglomerates.
		Granite and gneiss.
		Schists included in the granite and gneiss.

(The wavy line indicates an unconformity.)

There are a number of basic intrusions consisting of diabase and dolerite, the latter forming more or less horizontal sheets in the Karroo rocks. There are also several pipes and fissures filled with Kimberlite (blue-ground) and sometimes carrying diamonds.

II. The Granite and Older Schists.

Immediately south-east of the T'Kuip Hills at Omdraai's Vlei the granite has been brought to the surface by an anticlinal fold trending north-east, and evidently the extension of that affecting the rocks of the Doornberg. The main mass of the granite extends northwards from Roode Poort for a distance of ten and a half miles, and has a breadth of about six miles, the Brak River crossing it from south to north. That it has a much greater extension towards the south-east is shown by the numerous little inliers in the Dwyka conglomerate, notably on the farms West Prairie and Ruitjes Vlakte, while some outcrops appear close to the western extremity of Beer Vlei.

The granite is mostly a pink, medium-grained gneissic variety with foliation planes striking approximately north-east, and dipping towards the south-east. On Roode Poort the strike of the foliation is nearly east and west.

Porphyritic varieties are present, but are not very common; pegmatite and aplite veins are fairly abundant, and epidotised bands are frequent. On T'Kuip (East) some of the pegmatites carry fluor-spar. The granite is traversed by reefs of quartz, occasionally carrying a little copper, and by dykes of diabase and diorite.

On Lange Dam, nearly midway between T'Kuip and Hopetown, granite appears from below the Pniel quartzites in two little anticlines. The bulk of the rock is a fairly fine-grained pink gneissic variety, commonly a biotite-gneiss, rich in microcline felspar. The foliation planes are vertical, and strike about north-east.

Granite occurs in a similar manner a little west of Swingel's Pan, north of Beer Vlei.

As in the Mafeking Division so here also the granite and gneiss contain numerous inclusions of amphibolitic schists as

patches and lenticles traversed by veins of granitic material, both along and across their foliation planes, and showing all stages in the process of absorption with the production of banded hornblendic gneisses. These rocks are especially well seen along the banks and in the bed of the Brak River at the foot of the T'Kuip Hills.

A section (1,912) of one of these schist inclusions from the granite on Ruitjes Vlaakte shows the following features under the microscope. The rock is formed of actinolitic hornblende, usually nearly colourless, but sometimes pale greenish and pleochroic, abundant crystals of epidote with a smaller amount of zoisite, and a groundmass of colourless felspar containing little granules and prisms of epidote. It could well be termed a schistose diabase. A band, rich in quartz and orthoclase felspar, indicates an accession of granitic material, and in its neighbourhood the actinolite has a tendency towards idiomorphic outlines, while the epidote is aggregated together to form larger areas.

III. THE VAAL RIVER OR VENTERSDORP SYSTEM.

The diabases and amygdaloids with their basal quartzite formation (Pniel Series) were in the course of the survey traced as a chain of more or less detached areas surrounded by Dwyka tillite stretching from the Orange River in the vicinity of Hopetown past Beer Vlei to a point a little south of T'Kuip.

In the last Annual Report it was noted that the Pniel series overlay unconformably at Klokfontein, Modder River, and in the Kimberley mines certain rhyolites that were grouped with the Zoetlief series. Similar acid volcanics appear as a chain of inliers in the Dwyka arranged along a straight line extending westwards from a point a little south-east of Strydenburg through Beer Vlei to T'Kuip.

Although no actual contacts with the Pniel series are found, there can be no doubt that the acid lavas are an older and unconformable formation, and hence will correspond to the Zoetlief series of Griqualand West and Vryburg.

In the T'Kuip Hills the gap between these two formations is partly bridged over by a series of basic volcanics with interbedded arkoses, which appears to be unconformable both to the older and to the younger formations. To this group a distinctive name, the KUIP SERIES, has been given. Their existence had been recorded in the Report for 1899, but the relationships of the various volcanic rocks were not determined at that time.

A. THE ZOETLIEF SERIES.

At T'Kuip this series can be divided into an upper group of acid volcanics and a lower and less persistent group of conglomerates, arkoses and breccias, with occasional lava flows.[1]

[1] A. W. Rogers. Ann. Rept for 1905, p. 150.

Towards the southern end of the T'Kuip Hills, at a point about three-quarters of a mile north of the beacon belonging to Maritz Dam, the rhyolites rest directly upon the granite. About a quarter of a mile further on, the volcanics form a

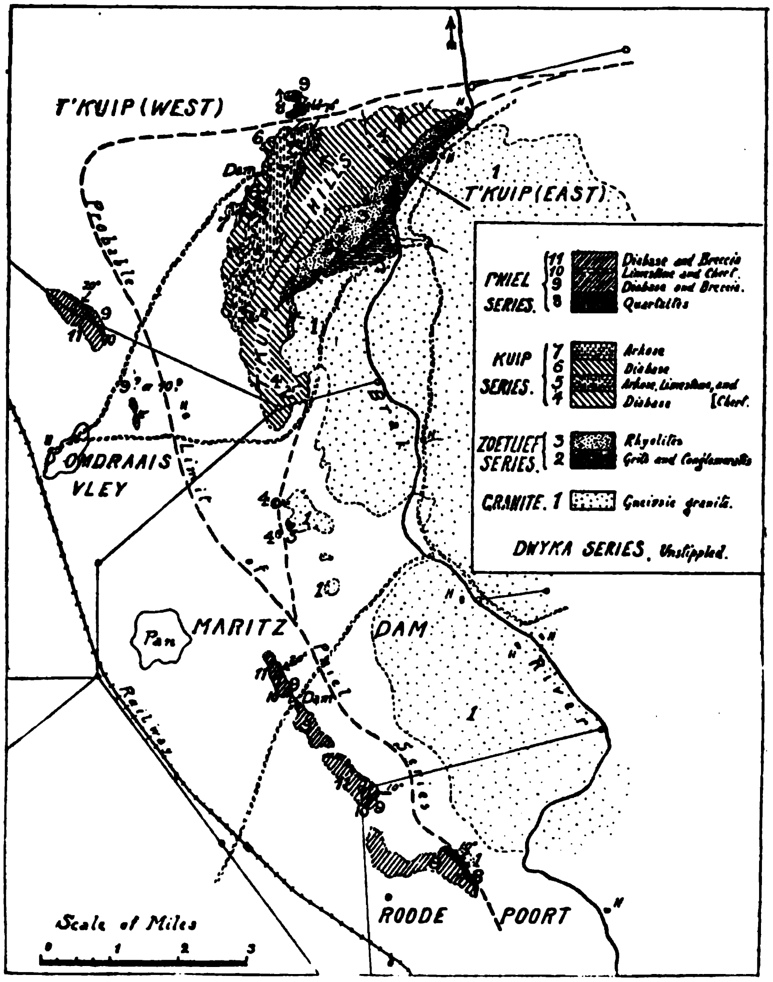

FIG. 1.—Geological map of the T'Kuip Hills.

small isolated eminence, at the base of which appear some hard green quartzites.

These rapidly thicken towards the north, coarse grits and arkoses making their appearance accompanied by breccias, tuffs and some thin bands of dark green volcanic rock.

The thickness of the sedimentary group probably does not exceed 300 feet; at the drift the existence of two parallel

strike faults, with a total downthrow to the east of about 150 feet, causes the thickness to be apparently much greater. This zone can be followed down the Brak River for several miles, but at T'Kuip (West) farmhouse, the last point where they can be seen and measured, they do not exceed 60 feet in thickness.

The gritty and conglomeratic rocks are dark in colour, and do not part readily along their planes of stratification; they weather into great rounded blocks and masses of very striking appearance.

The base of the series is very well seen in the bed of the Brak River a little below the drift. The surface of the granite is somewhat uneven, and the conglomerate overlying is coarse in places, the inclusions consisting of blocks of granite and occasionally of amphibolite.

In the higher beds the pebbles seldom exceed eight inches in diameter, and are usually well worn. They consist of quartz, quartzite, granite, and aplite, and are set in a groundmass composed almost entirely of granitic debris. A section of the pebbly arkose (1,908) shows under the microscope a rock composed almost solely of fragments of quartz and orthoclase and microcline felspar, together with a small amount of chloritized mica; the proportion of matrix is extremely small.

A section (1,907) of one of the dark green volcanics, interbedded in the arkoses, proves it to be an andesitic lava, having phenocrysts of oligoclase felspar set in a groundmass crowded with little prisms of the same mineral; the ferro-magnesian minerals have been completely altered.

These grits and conglomerates occupy the same position, both as regards the granite and the rhyolite, as those which have been cut in the main shaft of the Kimberley Mine below the 2,520 foot level.[1] Lithologically they resemble the latter very much indeed, having the same assemblage of pebbles. Both at Kimberley and at T'Kuip the sedimentary group thins out in a short distance, so that the rhyolites rest in places directly upon the granite.

The rhyolites are compact rocks not often vesicular, but showing a more or less banded character, which appears as a rule to correspond to the actual bedding planes of the lava flows. Some abrupt contortions of the banding may, however, be merely fluxion structures like those in the rhyolites at Klokfontein.

The lavas belonging to this formation, which occur at Bidouw's Kuil and Vilet's Kuil, on the north side of the Beer Vlei, were described in the 1899 Report under the name of amygdaloidal felsites. All the outcrops are in the form of hillocks with rounded outlines rising from a flattish tract of Dwyka.

Dips are difficult to make out, for the banding is, in certain

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[1] Ann. Report for 1906, p. 95.

cases, due to igneous flow, while, in addition, the rocks may be broken up by well-developed joints. Here and there layers of amygdaloidal or brecciated lava occur, and though the bands are impersistent they indicate a general northerly dip, probably accompanied by a certain amount of folding.

At Bidouw's Kuil the lowest lavas on the edge of the vlei consist of massive rhyolites, sometimes brecciated. Further north they become more amygdaloidal and apparently less siliceous, and consist of felsitic lavas often very vesicular and slaggy, and containing large quartz and chalcedony geodes. There are alternations of light and dark coloured lava. The same succession is found at Vilet's Kuil. The knobs of rock on the south-east side of the farm consist almost wholly of compact or brecciated and veined rhyolite, often with large porphyritic felspars. The northern outcrops are massive banded rhyolites, and the extreme north-western hummock is composed of darker amygdaloidal rock.

From the outcrops on Bidouw's Kuil and Vilet's Kuil the surface of the Dwyka tillite rises gradually for a distance of from one to three miles, and then Pniel lavas underlain by the quartzite group make their appearance, and dip at a low angle to the north.

The easternmost outcrop of the rhyolite was found in the midst of the Dwyka series on the farm Wonderdraai, a few miles south-east of Strydenburg and 34 miles from T'Kuip.

The rhyolites are pale greenish rocks containing blebs of quartz and commonly phenocrysts of felspar. In thin section they are found to be very much altered as a rule. The felspar phenocrysts consist of orthoclase and plagioclase, the latter frequently predominating. Usually they show alteration to a mixture of quartz, mica ,and chlorite ,but sometimes they are wholly or partially replaced by calcite. The ferro-magnesian constituents are hardly represented ,and then always by alteration products such as chlorite. In one specimen from Vilet's Kuil there are good pseudomorphs in isotropic yellowish serpentine after some mineral which was probably enstatite.

The groundmass is usually considerably altered, especially through silicification, but many examples show some colourless or brownish glass, and there are very fine perlitic varieties. The amygdales are usually filled with quartz and chalcedony.

The rhyolites frequently show the effects of movement by which the blebs of quartz have been shattered and the broken portions separated from one another. It is difficult to decide whether this has resulted through the brecciation or whether it has been caused by subsequent earth-movement. The abundance of brecciated rock and the presence of true tuffs points to the former of these two possible causes as the most likely one, but it is not improbable that the structures owe something to the second as well.

The common occurrence of plagioclase felspar in the acid

lavas indicates perhaps that some of the rocks are more closely allied to the quartz-andesites (dacites) than to the rhyolites.

Some of the lavas, especially in the upper portion of the series, contain no free quartz, and may be termed felsites or trachytes; they may also have plagioclase felspar in addition to the orthoclase.

The presence of lavas of intermediate composition in the upper portion of the volcanic series at Beer Vlei affords another parallel with the succession at Zoetlief in Vryburg and in the Kimberley mines.

The thickness of the volcanic group at T'Kuip is probably about 500 feet, but this appears to be much exceeded at Vilet's Kuil; at the latter place neither the base nor the summit of the formation is exposed.

On Maritz Dam, a few miles south of the extremity of the T'Kuip Hills, there is a rather peculiar occurrence of rhyolite, which is of interest for several reasons.

The volcanics form a little hillock rising from a flat of gneissic granite, and the junction of the two rocks is visible on the north side.

The exposure is about 250 feet long and 50 broad, with longer axis striking nearly east and west, and the rhyolites dip inwards from the north and from the south at a high angle.

The structure may be explained as a synclinal outlier of the rhyolites, but it is quite possible that it represents a volcanic neck from which the lavas of the Zoetlief series issued, the banding of the rhyolites representing fluxion structures parallel to the walls of the pipe. This seems a not-unlikely view, for nowhere have there been found any quartz-porphyry dykes which could account for these great rhyolite flows, nor, with this exception, do there appear to be any pipes corresponding.

Whether the occurrence is a pipe or a synclinal basin is immaterial, however, for in either case it makes it probable that at one time the Zoetlief volcanics were continuous between this point and the T'Kuip Hills.

Now about a quarter of a mile to the north the Kuip series rests directly upon the granite, while about 150 yards to the west of the rhyolite hillock is another little patch of basic lavas and breccias, the intervening ground being covered with soil and probably underlain by the Dwyka conglomerate.

It is perfectly clear then that the Zoetlief series has suffered considerable denudation prior to the formation of the Kuip series.

B. THE KUIP SERIES.

As shown in fig. 1, the rocks of this group succeed the rhyolites and build up the central and western portions of the T'Kuip Hills.

The formation consists of diabase and amygdaloid, with some thick intercalations of arkose, pebbly grit, sandstone, flagstone, limestone and chert. The beds have a constant dip of from 15°—40° to the west-north-west, and where most fully developed the formation must have a thickness of at least 1,500 feet.

The two southernmost outcrops on Maritz Dam have already been referred to. One of these is merely a little patch of volcanics surrounded by Dwyka, but the other consists of diabases and breccias underlain by about 50 feet of arkose, grit, and flagstone resting upon gneissic granite, and dipping at from 30°—45° to the west.

At a point a little north of the T'Kuip—Maritz Fontein beacon the diabases rest apparently upon the granite, but a little further north the Zoetlief rhyolites make their appearance, and underlie the diabases. The lowest flow of diabase rests directly upon a peculiar bed of brecciated rhyolite for some distance, until a strike fault brings up the granite almost to the level of the diabase.

From this point the thickness of rhyolite below the Kuip diabase increases from 150 feet to about 500 feet, attaining its maximum value below the highest point of the ridge; further north, the acid lavas become thinner. The rhyolites thus form the eastern slopes of the hills, and the diabase the high ground to the west.

The junction of the basal flow of the Kuip series with the rhyolites is not clearly exposed anywhere, and an unconformity can only be inferred from the fact that the former comes successively into contact with different lithological types of rhyolite, the dip and strike of the two formations being approximately the same.

At the north end of the T'Kuip Hills the junction is not clearly exposed, but in a little kloof about one mile to the south of that point there intervenes between the two groups of rocks a bed of hard green diabasic tuff from eight to ten feet in thickness.

The rocks forming the lower portion of the Kuip series are almost entirely diabases and amygdaloids, indistinguishable in hand specimen from those of the Pniel series; volcanic breccias are less common, however, than in the latter.

A thin section (707) from the south end of the hills shows a rock containing oligoclase felspar in phenocrysts and microlites and isotropic serpentine, probably pseudomorphous after enstatite, set in a groundmass which must have been glassy originally. The amygdales are filled with calcite and serpentine.

Low down in the series on the south-east side of the hills is a thin intercalation of arkose containing pebbles followed by porphyritic lavas.

The first big zone of sediments is found on the west side of the hills, where it gives rise to a belt of lower lying ground. At the northern end of the belt, where the rocks are well exposed,

the base of this sedimentary zone is formed by a thick bed of arkose resting upon a very vesicular lava flow. Hollows in the latter have been filled with gritty material, while the arkose contains angular fragments of diabase up to six inches across. Above the arkose come hard cherty flags, succeeded by a series of brown weathering limestones associated with cherts. These limestones run evenly with a westerly dip, but die out one by one as they are followed towards the south end of the hills. They are overlain by green and black cleaved flinty rocks, and these in turn by a thick bed of arkose.

This group of sediments is about 450 feet in thickness, but near the south-west end of the hills it is split up by two wedge-shaped sheets of diabase, and its thickness increased to over 600 feet. The rocks are chiefly arkoses, which weather unequally and produce a light sandy soil from which project large rounded hummocks of the more indurated material.

The second volcanic zone probably does not exceed about 150 feet in thickness, and forms the westernmost chain of kopjes in the T'Kuip Hills. The lavas dip westwards at a moderate angle.

The second sedimentary group was only found on the slope at the foot of ridges where the beds are partly hidden by sandy soil. The strata consist of arkoses several hundred feet in thickness.

The upward succession is as follows:—Dark green nearly compact diabase, thin light-coloured well-banded lava, thin green diabase, thin green flaggy beds, and yellowish or greyish arkoses.

The area to the west is formed by Dwyka, and the nearest inlier in that direction is formed of rocks belonging to the Pniel series.

The limestones and cherts are of great interest owing to their remarkable resemblance to those of the Pniel series close at hand, and to those of the Campbell Rand series exposed a few miles away to the north in the Biega Hills.

All the arkoses contain numerous well-worn pebbles of older rocks, seldom of any size, and invariably scattered at random through the beds. The pebbles consist principally of vein quartz, quartzite, granite, aplite, rhyolite, and diabase.

The presence of well-rounded pebbles of rhyolite low down in this formation gives considerable support to the view that the Kuip series is unconformable to the Zoetlief series, and tends to confirm the similar conclusion arrived at from stratigraphical considerations.

C. The Pniel Series.

As in the area to the north-east, this formation can be separated into two sub-divisions, a lower sedimentary group, composed

principally of quartzite, and an upper volcanic one formed of diabase amygdaloid and breccia.

It was recorded in last year's Report that the formation was traversed by an anticlinal fold extending from Campbell to Hopetown.

To the north of Hopetown a second anticlinal structure was discovered striking north-westwards from Pampoen Pan and crossing the Orange River below its junction with the Vaal. By its means the overlying Black Reef formation is brought up from the level of the river to a point fully 600 feet above the latter.

The Orange River has cut a deep narrow gorge through the anticline, and the basal quartzites have been laid bare from beneath their cover of volcanic rocks. The dip of the strata in the south-west limits of the anticline is in places about 45 degrees.

With the exception of the inliers at Pampoen Pan and the exposures in the gorge of the Orange River to the east, the whole of the north-central portion of Hopetown is formed by the Dwyka series. Between the Leeuwen Berg and Joostenberg there is a belt of ground in which a number of small inliers of diabase crop out through sand-covered Dwyka.

Towards the south-east the base of the formation is being approached, and between Hopetown and Beer Vlei there is a chain of inliers in the Dwyka in which the lower quartzite group plays an important part. Not only are the boundaries of the inliers most irregular, but the dips vary, and it is apparent that the formation is affected by two series of foldings, a gentle set which strike north-eastwards and a more pronounced set which strike north-westwards.

The quartzites appear at irregular intervals from beneath the volcanics, and only rarely form such extensive outcrops such as, for example, on Wit Poort, Wit Punt, and Scorpion's Kraal.

(1) *The Lower or Sedimentary Group.* The quartzites are light-coloured, as seen in the outcrop, but greenish in colour when taken from wells. They are commonly gritty, and sometimes very felspathic, and often contain pebbles of quartz, quartzite, cherty, and slaty rocks, etc. At a few places there are softer sandstones and occasionally some flagstones. On Lange Dam, where they rest directly upon gneissic granite, the beds probably do not exceed 75 feet in thickness, but on Klein Roode Dam they must have at least double that value. This thickness is maintained for some distance to the west, but just beyond Swingel's Pan, where the granite reappears, the quartzites do not exceed about 10 feet in thickness, the lower portions being full of fragments of pink felspar and pebbles of quartz and quartzite.

There is no doubt that the Pniel series has been deposited on an uneven surface of older rocks, and consequently consider-

able variation in thickness of its basal sub-division may be expected. In this case, however, it seems very likely that there is a local unconformity at the top of the quartzites, for first of all certain beds are missing from the latter, which are well developed both to the east and south, and secondly the volcanics which overlie them are not the peculiar breccias by which they are almost invariably succeeded.

A few miles east of Swingel's Pan, on Jantjes Fontein, Scorpion's Kraal and Alleman's Dam, there makes its appearance at the summit of the quartzites a thin group of calcareous quartzites and grits, brown weathering limestones, and dark cherts, succeeded by, and sometimes interbedded with, volcanic rocks, chiefly breccias.

These remarkable rocks, which recall those previously described from the Kuip series, are, as will be inferred from what has been said, absent at the west end of Swingel's Pan, but can be traced southwards round the edge of the high ground north of Beer Vlei, *e.g.*, on Vilet's Kuil, Bidouw's Kuil, Kalk Punt, and Kalk Kraal, and appear again in an inlier at the north end of the T'Kuip Hills.

This inlier shows hard white quartzites with some felspathic and pebbly portions dipping at a high angle to the north, and thus striking almost at right angles to the arkoses and volcanics of the Kuip series seen about 200 yards to the south.

The quartzites are fully 600 feet in thickness here, including a central band of dark blue limestone, and at their upper limit pass into calcareous grits with limestones and black cherts, followed by hard flinty shales, and then by volcanic rocks.

The quartzites are much less felspathic than the Kuip arkoses, but they include the same assemblage of pebbles, *e.g.*, quartz, quartzite, granite, aplite, chert, felsite, and rhyolite, the inclusions being seldom more than a few inches in diameter.

The quartzites are not seen again for a considerable distance, owing to the covering of Dwyka, but apparently curve round and strike in a south-south-easterly direction, the deflection being produced by the anticline traversing the T'Kuip Hills. On the farm Roode Poort the strata make their appearance resting on the granite and having a low dip to the south-west, the thickness being about 150 feet. The limestones are present at the summit of the sedimentary group, and are succeeded by volcanic rocks.

The presence on Roode Poort of the granite, as the basement rock shows that both the Kuip and Zoetlief series disappear in this direction, is confirmation for the existence of a marked unconformity at the base of the Pniel series. At the north end of the T'Kuip Hills the latter probably is in contact with the Kuip series, but the junction is covered by a narrow belt of Dwyka. North of Beer Vlei the rocks nearest to the Pniel quartzites are the rhyolites of the Zoetlief series; further to the north and north-east the underlying rock is granite.

(2) *The Upper or Volcanic Group.* A remarkable feature about this group is the occurrence almost throughout this area of a peculiar volcanic breccia resting almost immediately upon the sedimentary group. This breccia, which was recorded as being present in the gorge of the Orange River near Hopetown,[1] consists of masses, more or less angular or irregular, of a light-coloured felsitic rock set in a greenish diabasic groundmass. Sometimes the matrix is a hard black flinty material, probably of sedimentary origin.

The breccia can be readily recognised in the field, and hence its value in unravelling the structure of the area occupied by the Pniel series.

The breccias, through weathering, give rise to low mounds thickly strewn with blocks of light-coloured lava. They are accompanied by light-coloured compact or vesicular flows, evidently of a less basic nature than the diabases by which they are succeeded.

A prospecting pit sunk in this breccia on Karree Dam shows that the fresh rock consists of fragments of pink felsite set in a dark green matrix, which contains veins and patches of quartz, actinolite, epidote, and a pale brownish garnet.

The breccia is found to be present all over the area between Hopetown and T'Kuip, and has probably a wide extent, for it overlies the quartzites in the anticline on the Orange River south of Mazel's Fontein.

The succeeding volcanics are generally more normal diabases and amygdaloids, well seen, for example, along the Orange River north of Hopetown and again between Karree Dam and Karree Kloof north-west of Strydenburg. There is one horizon of great importance about 150 feet or 200 feet above the summit of the quartzites characterized by the occurrence of green flags, blue limestones, and black cherts like those in the "lower zone." The succession is well seen on Roode Poort south of T'Kuip, and in the chain of low hills that extends northwards into Maritz Dam. The hill north-east of Omdraai's Vlei is an inlier in the Dwyka, and shows the limestones and cherts intercalated between volcanic rocks and dipping at a moderate angle to the west.

This outcrop is of more than usual interest, for both the limestones and the cherts show very fine oolitic structures, and are identical with some of those of the Campbell Rand series.

This little zone is evidently by no means widely distributed, but was discovered again to the north-east on the farms Alleman's Dam and Drooge Dam, where the full succession is seen from the quartzites upwards, the latter having limestones and cherts at their upper limit.

The existence of these two calcareous and cherty zones is thus of very great value in rendering clear the stratigraphy of

[1] Ann. Rept. for 1906, p. 101.

the area, especially as the exposures of this formation are generally in the form of small or more or less isolated inliers in the midst of the Dwyka series.

There is not much to add to previous accounts of this formation regarding the nature of the volcanic rocks. The great bulk of the material consists of green compact or amygdaloidal diabase, in which the ferro-magnesian minerals have been completely chloritized, and the rest of the rock more or less silicified. The silicification has been usually more complete in the case of the lighter coloured, finer grained and presumably less basic types. The alteration has in many cases been so considerable that it is impossible to determine the exact nature of the rock originally.

Porphyritic lavas are rather rare. They were noticed in the angle of the Orange River in the north of Hopetown on the farms Roode Kop and Annex De Hoek (at the Mark's Drift Mine).

Sometimes the volcanic rocks are stained with copper compounds, *e.g.*, Pampoen Pan, where the minerals are found associated with quartz along a line of crush or fracture in the diabase.

IV. The Black Reef Series.

The Black Reef series appears at intervals between Douglas and Read's Drift, and possesses much the same characters as in the area to the north-east. At the Mark's Drift Mine the basal quartzites crop out along the Orange River and rest upon the Pniel diabase. At Mazel's Fontein the formation reappears and, as already mentioned, owing to the presence of an anticlinal fold, the outcrop is carried to an elevation of about 600 feet above the level of the river.

At the summit of the anticline, on Katlani, the Black Reef is much thinner and more shaly than usual, facts which suggest that the anticline may have been initiated at a time preceding the deposition of the Transvaal system, and that its development continued into the period occupied by the formation of the latter.

On the west side of the anticline there are a number of little patches of Black Reef quartzite dipping at angles of from 20° to 35°, and the beds cross the Orange River from McCowan's Kloof to Paarde Kloof. The diabase and Black Reef form a pretty considerable ridge against which the Dwyka tillite is banked.

The country further down the Orange River is formed in great part by the Dwyka, and the numerous boulders weathered out of the latter, together with the dense growth of thorn trees, chiefly the unpleasant "hakdoorn," render geological exploration difficult. From beneath the thick cover of Dwyka the Black Reef and Campbell Rand series project in a series of

cliffs and ledges, or else appear in the small gorges opening into the Orange River.

The Black Reef series forms conspicuous flat-topped hills along the south side of the river on the farm Blaauw Kop, and the rocks are more shaly here than is usually the case.

The lowest beds are hard white quartzites, which alternate with soft shales of various colours—green, blue, black, whitish, or red—followed by green flags and greenish-black quartzites, which cap the hills.

The uppermost beds and their passage into the Campbell Rand series is seen on Vaal Krantz, and in the gorge of the Orange River on Dopper Fontein and Zand Fontein. At this point they disappear beneath the Dwyka, and are only seen again at the south end of the Doornberg in Prieska.

The thickness of the formation near Blaauw Kop is not capable of exact measurement, but cannot be far from 300 feet.

Relation of the Black Reef to the Pniel series.

The unconformity at the base of the Black Reef is only brought out by a careful examination of the junction of the two formations.

At the Mark's Drift Mine, where the exposures can be rather well seen along the Orange River, there is at first sight a perfectly conformable succession. The sequence is as follows:—(1) Amygdaloidal diabase, (2) flow of massive porphyritic lava about 10 feet thick, (3) green diabase from 3 to 5 feet, (4) massive grey quartzites. For quite a considerable distance along the right bank of the river this succession holds good. On the left bank of the river at the mine the copper lode which is being worked occurs in a wide body of compact diabase, which is quite different petrologically to anything in the neighbourhood, and which must therefore be an intrusion in the Pniel volcanics. Immediately across the river are the Black Reef quartzites with no signs of any intrusion, but the reef is marked by a few veins of quartz, which cannot be traced for any distance however.

It is very probable, therefore, that we have here an intrusion which is younger than the Pniel series, but older than the Black Reef quartzites, and that there is a deceptive conformity.

Again, in the western limits of the anticline on Paarde Kloof the two formations possess a similar dip and strike the thickness of the volcanics measured from the top of the Pniel quartzite to the Black Reef along the left bank of the Orange River, being about 500 feet.

On the right bank the volcanics are thinner, and as the Black Reef is traced away from the river it approaches and nearly comes into contact with the Pniel quartzites. Still further north it rests upon a considerable thickness of diabase,

Close to the beacon common to Mazel's Fontein, Floris Fontein, and Katlani, there is, near the base of the quartzites, a layer of greenish conglomerate containing well-rounded pebbles, chiefly of diabase and grey limestone, up to five inches in diameter. The diabase is evidently derived from the underlying Pniel volcanics, but the source of the limestone is not evident.

V. THE CAMPBELL RAND SERIES.

The limestones and dolomites forming the Kaap Plateau extend as far to the south-west as Dopper Fontein, where this remarkable tableland comes to an abrupt termination.

The escarpment, which has an altitude here of about 3,925 feet above sea-level, now bends to the north-west and continues at this level almost as far as Griqua Town.

The Orange River has cut through this formation just before reaching Read's Drift, and flows for five miles in a deep gorge, bounded by cliffs of dark limestone several hundreds of feet high.

All round about Read's Drift the Pre-Karroo rocks are deeply buried by Dwyka tillite, but at one locality about four miles below the drift the Campbell Rand series reappears along the river for a short distance

The whole of the valley of the Sand River (Lanyon Vale) and the north-eastern portion of Prieska are in all probability underlain by this formation, but the rocks do not project through the Dwyka until we reach the Biega Hills.

The strata consist of the usual brown weathering limestones and dolomites, with occasional beds of flagstone. Chert is common in the upper half of the series, and forms low hills on the plateau south-south-east of Griqua Town. Peculiar dark red chert occurs along with the more common grey or black varieties in the central hill on Biega.

VI. THE GRIQUA TOWN SERIES.

The banded ironstones of the lower division of this formation commence in the bend of the Orange River at Prieska, and extend northwards past Griqua Town, the altitude of the range increasing gradually and continuously through that distance.

The Eastern side of this range, usually known as the Asbestos Mountains or the Griqua Town Hills, is well defined, and at the foot of the low escarpment of ironstones lies the Dwyka, the feature being, therefore, a repetition of the eastern edge of the Kaap Plateau.

Towards Griqua Town the Dwyka is concealed beneath thick deposits of calcareous tufa and gravels, which form a continuation of the peneplain of the Kaap and the junction of the Griqua Town with the Campbell Rand series is entirely hidden.

The low range is gashed in a number of places by narrow,

steep-sided, transverse gorges, often several miles in length, and through these the drainage from the north-west makes its way to the Orange River. On the west of the ridge proper the country becomes more open, while deep red sand covers up the rocks in the valleys.

The dips of the rocks are generally westwards or north-westwards at low angles, but on Brak Fontein and Blaauwbanks Fontein there are sharp anticlinals, which strike nearly north and south.

Occasionally the strata are crossed by gentle folds striking north-west, for example, on the farm Spioen Kop.

The ridges show numerous clefts in more or less straight lines, which are due in most cases to the presence of dykes of diabase. In several cases no igneous rock could be discovered, and the features may perhaps be due to the weathering of beds along lines of crush. The walls of the ravines in the Griqua Town series are generally precipitous, and show numerous little caves. It is usually possible to make an ascent by the cleft determined by a dyke or line of crush.

The strata are the usual brown, red, or black banded ironstones and jaspers, of which a description has already been given by Mr. Rogers.[1] Extremely tough dark blue and brown banded rocks, rich in crocidolite, occur at a number of points, notably on Elands Fontein and Roode Pan. Fibrous crocidolite (asbestos) is being mined on the first-mentioned farm and on Krans Hoek; the mineral is, however, widely distributed.

The various oxidation and silicification products of the crocidolite, colourless, blue, or yellow-brown, are frequently found, the last named being the most abundant variety.

VII. The Dwyka Series.

As in the area to the north-west, this formation can be separated into a lower division characterized by boulder-beds, and an upper division composed of dark shales, which are separated from those of the Ecca by means of the "White Band." Along the south-eastern edge of the Dwyka belt the boulder-beds are thin, but along the Vaal-Orange River valley the deposit attains a considerable thickness. This feature is a repetition of that seen towards the north-east.

Surface upon which the Formation Rests. Everywhere the Dwyka rests unconformably upon an undulating or very uneven floor of older rocks. The rocks forming the great ridge on the right bank of the Orange River near Douglas pass below the Dwyka in the north of Hopetown, and no exposures of pre-Karroo rocks appear again until the Brak River is crossed. Be-

[1] Ann. Report for 1905, p. 156 and onwards.

tween Hopetown and Omdraai's Vlei the older rocks appear at intervals through the Dwyka, and the outcrops evidently indicate a partially-buried ridge.

Towards the south-east the level of the base of the Karroo formation falls, as has been clearly proved, by the deep borehole at De Aar. In the north of Hopetown and in Prieska is found the continuation of the pre-Dwyka valley of the Harts-Vaal River, its north-western limit being the Kaap Plateau and Griqua Town Hills, with a tributary from the north now occupied by the Sand River. Variations in altitude of the base of the Dwyka, amounting at times to over 1,000 feet, are evident from a study of the Orange River sections.

The Dwyka is found resting against the face of the Griqua Town Hills, and no doubt at one time overlay the whole of the Hay division. Some of the north and south valleys in which the rocks are concealed by red sand, *e.g.*, Niekerk's Hope, are very probably of pre-Dwyka age, and have been re-excavated since.

An idea of the nature of the surface on which the Dwyka was deposited can be gathered from an examination of the Orange River valley near Blaauw Kop. Here we find numerous ledges of rock (Black Reef and Campbell Rand formations) projecting from the mantle of glacial deposit, and indicating a former landscape of most diversified aspect. In pre-Dwyka times the ground must have risen in a series of steps for over a thousand feet, and must have been of an extremely rugged nature. The old escarpments frequently show glacial striations wherever the overlying deposit has been removed by denudation.

Direction of Glaciation. Striated surfaces occur at a number of points, generally along the Orange River. In most of these the direction of glaciation is from the north-east to the south-west, but there are several localities where the divergence from this direction is considerable. In the following table the bearings are in each case measured from the true meridian:—

Naauwtes Fontein (Hopetown)	S. 53° E.
Brand Fontein (Hopetown)	S. 63° E.
Slyp Steen, No. 2 (Hopetown)	S. 80° W.
Kameel Drift (Hopetown)	S. 50° W.
De Kalk (Hopetown)	S. 35°-50° W.
Mark's Drift (Hopetown)	S. 20°-35° W.
Blaauw Kop (Hopetown)	S. 30° W.
Mazels Fontein and Vaal Krantz (Herbert)	S. 40° W.
Read's Drift (S.W. of), (Hay)	S. 35° W.
Karree Dam (Hopetown)	S. 28° E.
Vilet's Kuil (Hopetown)	S. 25° E.
Wonderdraai (Hopetown)	S. 10° E.
T'Kuip Hils (north), (Prieska)	S. 30°-45° W.
T'Kuip Hills (south), (Prieska)	S. 20° W.
Ruitjes Vlakte (Britstown)	S. 5° W.

The Pniel diabase retains the striations very well along the Orange River, but in the central portions of Hopetown, in spite of the numerous exposures of that rock as inliers in the Dwyka, only one spot was found where the groovings were still apparent. This was on Karree Dam, where the surface had been exposed in the overflow from a dam. At Mazels Fontein there are some fine surfaces in a stream bed along the road north-west of the homestead. The rocks consist of the limestones and flagstones of the Campbell Rand series, and whereas the striations are well preserved on the latter, only the wider groovings are retained by the limestones. This is due to the rapid weathering of the limestone upon exposure; even calcareous patches in the flagstones behave in the same way. Limestone boulders in the Dwyka are as a rule rough, and never show any striations. If, however, they are dug out of the rock, then the protected surfaces are found to be polished and striated.

The Griqua Town ironstones do not form suitable material for preserving the effects of glaciation. The rocks are well bedded, and generally dip towards the west, *e.g.*, more or less in the direction of the glacial movement. At the junction with the Dwyka, the ironstones have been tilted up, great blocks have been torn out bodily, and striations cannot be clearly made out. At Blaauwbanks Fontein, however, at the great bend in the Orange River, the Griqua Town beds form a sharp anticline now emerging from its cover of Dwyka. Just where the road to Prieska crosses from the Dwyka on to the Griqua Town beds, the latter present a nearly vertical finely striated face, the scorings passing obliquely upwards, and being directed towards the south-west. The outcrops of rhyolite at Vilet's Kuil exhibit all the features typical of *roches moutonnées*, and in spite of the prolonged weathering to which they must have been exposed, nevertheless still retain in a few places beautifully glaciated surfaces.[1]

The granite is not a suitable material for the preservation of striations, but a small outcrop on Ruitjes Vlakte showed some well-marked groovings.

There is a peculiar characteristic of a few of the glaciated outcrops which is worthy of note. Instead of the knobs being smoothed and evenly curved like those so well seen along the Vaal River, the exposures show jagged surfaces, with the corners and edges ground down and polished. This is well seen in the rhyolite inlier on Wonder Draai, near Strydenburg, and in the exposure of diabase on Karree Dam. Apparently the ice sheet was unable to grind down these knobs of rock sufficiently so as to form smooth curved surfaces; but instead, tore out blocks of material and rounded off the rugged surface which resulted. May it not, therefore, be that the ice sheet exercised a less erosive action in central Hopetown than in the area to the north-

[1] Ann. Report for 1899, pp. 96-7.

east? There can be no doubt that still further to the south and south-east, in the area hidden by younger Karroo deposits, the Dwyka boulder-bed was deposited in water, probably through the agency of floating ice. At some intermediate point, therefore, the ice-sheet must have ceased to rest upon and grind down the rocks forming the Karroo floor.

Transport of Boulders. Many of the boulders in the "boulder-beds" are of rocks which are found *in situ* to the north-east, thus conforming the evidence afforded by the glacial striæ.

Inclusions of the rhyolites of Klokfontein and the Riet River are found along the Orange River from Naauwtes Fontein to Mark's Drift and Dopper Fontein, and they have also been noticed round about Karree Dam, Kalk Punt, etc., north-west of Strydenburg. Boulders of quartzite and diabase breccia are abundant in the Dwyka along a belt extending from near Hopetown to Beer Vlei, in which the Pniel quartzites and volcanics appear.

Masses of Campbell Rand limestone form an essential constituent of the Dwyka of the Sand River area and around Read's Drift, Dopper Fontein, etc. The blocks of limestone are sometimes many feet across, but tend to break up on exposure to the weather, and the slopes of Dwyka are strewn with little fragments of the brown-weathered limestone. The rock, derived as it is from the lower half of the Campbell Rand formation, is fairly free from chert, and is thus distinguishable from the inclusions from the Dolomite of the Transvaal. Boulders of the Griqua Town jasper are only found within a short distance of the foot of the Griqua Town Hills, for example, on Krans Hoek, Spioen Kop, and Blaauwbanks Fontein. On the latter farm the inclusions first appear about half a mile east of the nearest exposure of Griqua Town beds. Immediately west of the anticline of jaspers, the Dwyka is crammed with great blocks of the latter material, some of them angular or jagged, and evidently torn *en masse* from the ridge, while others are rounded and well striated.

Generally speaking, boulders of diabase and amygdaloid are the predominant constituent of the Dwyka, which is not surprising, considering the huge area to the north-east which is composed of these rocks. Quartz-porphyry and granite are not uncommon, while blocks of a red variety of granite, probably from the Central Transvaal were also observed, notably at Sand Drift and Blaauwbanks Fontein.

The Boulder-beds. Along the south-eastern side of the Dwyka belt the boulder-bed is generally thin, and often intensely hard, and is usually succeeded directly by bluish and greenish shales. This is the case at Hopetown, De Kalk, Drie Kopjes, Geluks Poort, and Gemsbok Vlakte, to mention a few instances.

Further north, where the Dwyka fills up a great depression, the deposits are much thicker, probably in places over 400 feet,

and consist of alternations of conglomerate, "gravel Dwyka," and boulder shale, with occasional shaly and calcareous layers. There are numerous fine sections of this phase of the Dwyka along the Orange River, between Read's Drift and Prieska, especially at bends where the river has cut laterally into a gravel-capped terrace, and laid bare a face of Dwyka from 250 to 300 feet in height, for example, at the Sand Drift Mine. In this last-mentioned locality the upper portion of the cliff is formed of a huge thickness of intensely hard gravelly Dwyka, underlain by softer bluish tillite.

The maximum thickness of the deposit is difficult to estimate, owing to the considerable variation in altitude of the floor of older rocks. The Dwyka is the formation exposed in the valley of the Sand River from Read's Drift for a considerable distance northwards. The Kaap terminates in an escarpment on Wit Berg and Naras, and the rock building it up here is the Dwyka, with a thick capping of tufa and gravels. The Campbell Rand beds and the Dwyka have equally been cut to a flat, with an altitude of about 800 feet above the Orange River at Read's Drift. The Sand River valley represents, therefore, a great depression, which has been filled in with Dwyka, and the thickness of the latter may therefore have exceeded 800 feet.

The boulder-beds reproduce in their dips the undulations of the floor upon which they rest, and at several places the inclination of the beds is over 30°, for example, close to the Orange River on Blaauw Kop. At Blaauwbanks Fontein, however, the bedding of the Dwyka remains horizontal, in spite of the fact that the Griqua Town beds form an inlier rising in a most abrupt manner to an altitude of about 400 feet above the level of the river.

The Upper Shales and White Band. Dark-coloured shales, succeeded by the White Band, overlie the boulder-beds and crop out in a narrow belt, which extends from Hopetown past Limiet's Kop and Strydenburg, and which passes to the south of Beer Vlei. A thick sheet of dolerite is invariably intruded either immediately below, in, or above the white band, and the upper limit of the Dwyka formation is in consequence generally defined by a line of low dolerite hills. Dolerite-capped outliers of shale lie to the north-west on Joostenberg, Leeuwberg, Kaffir's Kop, Geluck's Poort, Drie Kopjes, Elands Nek, and Maideberg, a little to the north-west of Beer Vlei.

In the dolerite outlier on Uitdraai, a little to the east of Prieska, the intrusion occurs at the junction of the shale and boulder-bed.

The shales are the usual bluish or greenish varieties, which are sometimes of a rather flaggy nature. Whitish sandstones are not represented. Calcareous nodules sometimes occur, more commonly huge brown ferruginous concretions, *e.g.*, Perskie Dam. The shales have fucoid-like markings and casts of worm burrows. The carbonaceous white weathering shales constitu-

ting the White Band are well seen at a number of points from Hopetown in a south-westerly direction, for example, on the Commonage, Ganna Hoek, Limiets Kop Fontein, Perskie Dam, Plat Kuil, Vlak Fontein, Taaibosch Draai, etc. On Limiets Kop Fontein several wells show very finely the passage from the snow-white weathered shale into the unaltered black carbonaceous material. The zone is probably about 50 feet in thickness.

The shales of the white band are soft and flaky and very fine-grained. Along with the snow-white material are pink and red varieties, due to the staining of the shales by oxides of iron from the decomposition of iron sulphide. In a well on Middel Dam the black shales are full of pyrites and marcasite, and yield on decomposition ochre and gypsum. Heavy ferruginous layers and ocherous concretions are numerous in the white shale.

Fossils. Only a few fossils have been obtained from this formation within this area.

At Wonderdraai, near Strydenburg, there rest against the rhyolite inlier described earlier in this Report a few feet of intensely hard conglomerate or breccia, in which fragments of the rhyolite predominate. The groundmass forms only a small proportion of the rock, and is a hard black flinty shale, and in this material, wedged in between boulders of rhyolite, were found some fragments of an uncrushed but carbonised plant stem and a portion of a frond of *Gangamopteris.* The fossil thus occurs within a few feet of the base of the Karroo system of rocks.

At Elandsdraai, close to Orange River Station, the core from a bore-hole in the Dwyka shales yielded two fossils. One of these is a small crustacean, not yet described; the other is a portion of a stem which has been identified by Prof. Seward with *Lepidodendron australe* (Mc'Coy),[1] a form occurring in the Lower Carboniferous and Upper Devonian of Australia. These fossils were obtained by Mr. F. B. Parkinson, A.R.C.S., and presented by him to the South African Museum, Cape Town.

VIII. THE ECCA SERIES.

Succeeding the rocks of the White Band is a considerable thickness of dark bluish or greenish shales, with occasional calcareous concretions. These beds can to a certain extent be subdivided according to lithological differences. At the base come several hundred feet of hard creamy coloured splintery shales, with a tinge of green, and which are not so white and flaky as those of the White Band, nor do they contain pink or reddish bands. Limestone concretions are not very common, and are usually light in colour, with a crystalline structure. This zone

[1] Geological Magazine, p. 484, 1907.

is well developed to the east and south-east of Strydenburg, and to the south-east of Beer Vlei.

It is succeeded by soft dark blue or blue-green crumbly shales, with abundant concretions of dark red-brown weathering limestone, full of little veins of greenish shale, and often exhibiting cone-in-cone structure. These shales form flats between Strydenburg and Potfontein, *e.g.*, De Put, Rhenoster Valley, Diedericks Put, etc., and frequently build up dolerite crowned hills, *e.g.*, Jackals Toren, Strykuil Kop, Tigerberg, De Put, etc.

The uppermost beds of the Ecca are hard greenish and bluish shales and flagstones, in which calcareous concretions are not common. These flaggy beds build up the Rhenoster Berg near Behr's Hoek, and appear along the railway between De Aar and Potfontein. Near the summit of the Rhenoster Berg whitish sandstones in thin beds make their appearance, alternating with crumbly sandstones and mudstones, and the pile of sediments is capped by a horizontal sheet of dolerite. This arenaceous horizon appears in the ranges east of the railway in the direction of Philipstown and Hanover, and seems therefore to be persistent. As this is the first horizon at which sandstones make their appearance in the Karroo beds, it will probably be of much assistance in the work of dividing this formation into zones. It is noteworthy that a similar section of the Ecca has been recorded in Calvinia,[1] and that the base of the Beaufort series has there been taken at the horizon where massive yellow weathering sandstones succeed dark bluish flaggy shales.

A few plant stems were found in one of the sandstones of the Rhenoster Berg, also some pieces of silicified wood, but the flaggy shales of the Ecca are often crowded with indeterminate fucoid-like impressions.

At De Aar Station a borehole, 1,630 feet in depth, was put down by the Railway Department,[2] penetrating Ecca shales and dolerite; as far as can be judged from the samples of core, the Dwyka formation was not reached, and this borehole is therefore of immense value in indicating the fall in level of the Karoo floor towards the south. The altitude of De Aar is 4,080 feet above sea-level, and the bottom of the borehole stands thus at 2,450 feet.

The section of the borehole shows a series of bluish shales, which carry in their lower portion calcareous concretions, and which are split up by sheets of dolerite, namely, 52-139 feet, 432-695 feet, 1,020-1,080 feet, and 1,605-1,630 feet. These dolerite sheets include thin layers of metamorphosed shale and mudstone.

The thickness of Ecca beds at De Aar is thus 1,300 feet at the least, but the total thickness of the formation, as indicated by the sections in the Rhenoster Berg, will exceed this value somewhat.

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[1] Annual Report Geol. Commn for 1903, p. 33.

[2] Report on Water Boring on the Cape Government Railways for 1903, p. 4.

IX. The Intrusive Rocks.

A. Pre-Karroo Intrusions. At the Mark's Drift mine, as mentioned earlier in this Report (p. 175), a metalliferous lode occurs in a mass of diabase, which is very probably intrusive in the Pniel volcanics. In thin section (1890) the diabase is found to contain large pseudomorphs in serpentine, probably after a pyroxene; pseudomorphs in carbonates after felspar, and shows ilmenite altered to leucoxene. The groundmass consists of micropegmatite.

The lode stuff is composed of quartz and calcite, with chalcopyrite, galena, and blende.

At Blaauw Kop, adjoining the Orange River, is a diabase dyke, about 50 feet wide, cutting through the Black Reef series. In the neighbourhood of the river it is overlapped by the Dwyka, but reappears further north, where it is intrusive in the limestones of the Kaap.

The dyke is remarkable for the number of narrow veins of quartz and calcite which traverse it. They are regular, and run more or less parallel to the walls of the dyke. The rock itself shows a banded structure, but has been so altered that its original nature cannot be made out under the microscope. The material appears worthy of further examination.

Another dyke is found crossing the Orange River a little to the north-west of Blaauw Kop. It is (1892) a fresh rock, with a sub-ophitic structure, and shows nearly colourless augite frequently twinned, biotite, magnetite, and a little hornblende fringing the augite. The groundmass is of felspar and quartz, forming micropegmatite.

At Dopper Fontein there is an interesting basic dyke, which can be traced up the face of the escarpment almost to the summit of the plateau. Then it spreads out, and terminates in the limestones and shales, the latter being tilted away from the dyke and greatly contorted and metamorphosed. Both the latter and the dyke at its apex are veined by quartz. Two other dykes are found a little to the north-east, and are accompanied by quartz carrying a small amount of copper minerals.

On T'Kuip East a diorite dyke cuts through the granite in a south-easterly direction. The rock has weathered at a greater rate than the granite, and the dyke produces a distinct road-like feature, flanked by odd-looking knobs of granite.

The thin section (1911) shows idiomorphic colourless augite, serpentine pseudomorphs probably after enstatite, brown hornblende and biotite usually intergrown, magnetite and apatite. The remainder of the slide is composed of slightly clouded plagioclase felspar, the structure of the rock being holocrystalline.

Diabase dykes are frequent in the T'Kuip granite. Most of these are fine-grained, but several are highly porphyritic at their

contacts with the granite, the felspar phenocrysts being occasionally over one inch in length.

B. Karroo Dolerites. In this area dykes of dolerite appear to be rather uncommon, and the intrusions are nearly all in the form of more or less horizontal sheets, penetrating the Dwyka and Ecca shales. Hence the numerous dolerite-capped hills, which are so well represented in the southern portion of this area, *e.g.*, Leeuwen Berg, Joostenberg, Drie Kopjes, Elandsberg, Limiets Kop, Strydkuil Kop, De Put, Rhenoster Berg, etc.

The northern portion of this area is practically devoid of dolerite, and the only sheet of any importance is that on Uitdraai, adjoining the Orange River east of Prieska.

The dolerite sheets have, as in the area to the north-east, the same tendency to variation in altitude, in accordance with the undulations of the floor of the Karroo beds. This is well marked between Hopetown and Omdraai's Vlei.

Generally the lowest sheet has been intruded in or close to the horizon of the "White Band," while other sheets penetrate the shales of the Ecca. The deep borehole at De Aar proves the existence of several of these sheets, one below the other.

The dolerite is usually the typical ophitic rock, with or without olivine. Some of the intrusions possess a sub-ophitic structure, however.

The intrusions have in many places converted the shales into porcellanite and lydianite, and calcareous nodules into impure crystalline limestones.

X. The Diamondiferous and Allied Pipes.

Several occurrences of ultra-basic breccia or kimberlite, commonly known as "blue-ground," have been found in this area, and of these one at least is diamond-bearing.

(1) At Sand Drift, in the Hay Division, not far from Prieska, the Orange River flows at the base of a cliff about 275 feet in height, formed of Dwyka boulder beds, capped by tufa and river gravels. Diagonally up the face of cliff runs the outcrop of a vertical fissure from 4 to 8 feet in width, filled with kimberlite, and striking nearly north-east. This fissure can be traced for some distance north-eastwards, until it comes into contact with a sill of dolerite, and is broken into narrow irregular veins and stringers. On the line of fissure is a small circular pipe, about 50 feet in diameter, which is later in age than the fissure. There appear to be three phases of intrusion at Sand Drift. First a sheet of hard fine-grained micaceous kimberlite parallel to and overlying the dolerite sill. Secondly a vertical fissure filled with soft yellow weathering kimberlite, cutting transversely through the earlier intrusion. Thirdly the pipe filled with pale bluish kimberlite. Fragments of black (Dwyka) shale and tillite are most abundant in the pipe, whereas in the fissure they are but poorly represented, and are accompanied by boulders of

peridotite. Mr. Robert Scott, late manager of the mine, informed me that the diamonds obtained from the fissure were darker, more irregular in shape, and of poorer quality than those from the pipe.

(2) In the extreme north-eastern corner of Viool Kraal (Britstown), in the midst of dolerite hills, is a small pipe, which is interesting for the number of small inclusions of granite and gneiss in the kimberlite. The pipe penetrates dolerite and the " white-band " of the Dwyka series.

Another small pipe exists in the north-western corner of the farm, in a small kloof leading to Karree Hoek.

A boulder from this pipe proves under the microscope (1893) to be a gabbro of rather uncommon type. The rock is composed of plagioclase felspar approaching labradorite in composition, accompanied by a small amount of more acid felspar and a little quartz. Augite is present, altered generally to diallage, and intergrown with or surrounded by hornblende. The latter has a pleochroism from yellow to dark green, and occurs in interlocking areas with a tendency to idiomorphic outline. Numerous little hornblendes are included in the felspars. The rock shows an approach in structural character to the granulitic gabbros.

(3) Small pipes occur on Uitkyk and Barends Fontein, in Britstown, while the contacts of kimberlite and shale have been exposed in wells on T'Orroo and Middel Dam, in Hopetown. In none of these occurrences, however, has any attempt been made to prove either the size of the pipes (or fissures), or the existence of diamonds in the kimberlite.

(4) On the farm Rietfontein (incorrectly known as De Put) along the western border of the Philipstown division are some peculiar occurrences, which probably are to be connected with the kimberlite intrusions. On the western boundary of the farm there rise from a flat of shales three little hills, united at their base and crowned with dolerite. On the slopes of each of the three hills are boulders of dolerite and portions of hard shale, more or less tilted and shattered. Excavations show a peculiar greenish blue breccia, soft and somewhat clayey, and full of fragments of soft and hard shale, limestone (nodules), and dolerite. The latter is in more or less angular blocks, up to three feet across. The shale fragments have the angles rounded off, and show smooth greasy faces, sometimes well striated. No foreign boulders were noticed in the breccia. The material thus recalls the " floating-reef " of the Bultfontein and Kamfersdam mines. The dolerite at the summit of the three little hills probably represents the remnants of an intrusive sheet, such as is seen in a kopje a short distance to the south, but the material has evidently been somewhat disturbed.

Pieces of ilmenite were found in the breccia, while ilmenite and garnet were picked up on the shale flat at the foot of the hills. Hard micaceous kimberlite is exposed in small pits a few hundred yards to the north.

The occurrence is probably an embryonic pipe, whose boundaries coincide more or less with those of the fractured area. The disturbance has not been very great; much of the material is almost *in situ*, while the remainder has been brecciated, and the fragments polished by attrition, without very much vertical movement. It seems most likely that denudation has just laid bare the apex of the volcano, and that further down in the pipe the intrusive kimberlite will be found.

XI. The Recent and Superficial Deposits.

Frequently over wide areas the formations are concealed by soil, sand, or calcareous tufa, and to a lesser degree by river gravels.

In the area occupied by the Ecca shales wide flats extend between the dolerite-crowned hills. These flats are formed of light drab-coloured soil, more or less clayey in character, supporting a scanty growth of small Karroo bushes. After every rain, a thin layer of silt is spread over the surfaces of these flats, and the drainage either makes its way into ill-defined stream courses or gravitates towards a pan.

Red Sand is abundant in the central portion of Hopetown, extending eastwards almost to the Orange River. Usually it supports a growth of the little bush *Rhigozum trichotomum* (Burchell) commonly known as Driedoorn, but in the neighbourhood of the Leeuwen Berg, and again at the junction of the Vaal and Orange Rivers grass is abundant. In the south-east, red sand is not very common, but a belt of it extends from Hopetown past the eastern side of Elandsberg. The sand is composed of sub-angular or nearly rounded grains of quartz, coated with iron oxide.

In the valleys west of the Asbestos Mountains there is much deep red sand. The material is carried down in the rainy season to the Orange River, and hence the patches of sand country in the neighbourhood of Sand Drift and Muis Hoek.

Calcareous tufa is abundant, especially in the valley of the Orange River below its junction with the Vaal River. It commonly overlies the Dwyka boulder-beds in the north-west of Hopetown and east of Prieska, and the calcareous matter has doubtless been derived in great part from the underlying formation. Tufa conceals the rocks at the base of the escarpment of the Kaap, and is found in quantity on the plateau itself.

Alluvial terraces. The most interesting feature in this area is the existence at various altitudes of alluvial terraces, which, by their presence, indicate considerable modification of the original drainage system.

The oldest and most important of these is the Kaap Plateau, the post-Karroo origin of the feature having been suspected for some time, although until now no definite proof has been forthcoming. The nature of this plateau has been briefly described by Mr. Rogers[1]; to his account must be added a note on the southern extremity of the area in question. It has already been remarked that in the Sand River Valley both the Campbell Rand and Dwyka series have been cut perfectly flat and covered with a great thickness of tufa and gravels. The gravels consist principally of brown and black banded jaspers, red jaspers, and grey or black cherts, the pebbles being abundant in the lower portion of the tufa. The fragments are commonly flattish owing of the fissile nature of the material, but their corners and edges are well rounded, while the cherts are well worn. They sometimes exceed six inches in length.

These pebbles have been derived principally from the Griqua Town Hills, about 12 miles to the north-west, and now separated from the plateau by the valley of the Sand River.

Similar gravels are found along the edge of the escarpment at Floris Fontein, and from thence to Campbell. At Boetsap the surface of the plateau is, in the same way as in the Sand River Valley, continued from the Campbell Rand on to the Dwyka series.

The Kaap Plateau is, therefore, a peneplain with, in the southern part, a gentle slope towards the east, the altitude of the present escarpment being almost exactly 4,000 feet over the distance of 170 miles from Vryburg to Read's Drift. A few minor irregularities of the surface have been developed through the existence of the very resistant cherts of the Campbell Rand series. At Takwenen,[2] near Vryburg, however, Mr. Rogers has noticed that the Black Reef and volcanic beds have been cut flat equally with the surrounding limestones.

How far this peneplain continued eastwards is not clear; over a wide area in that direction the country is at a lower level than the 4,000 foot contour owing to the erosion performed by the Orange, Vaal, and Hart's Rivers and their tributaries. The greater portion of this tract is formed of shale flats and dolerite hills, the latter usually attaining an altitude of from 4,000-4,300 feet above sea-level.

It is noteworthy that gravels containing brown jasper pebbles occur south of the Orange River near Blaauw Kop, and that fragments of brown jasper, crocidolite, green quartzite, agate, etc., are picked up many miles to the south-east, either of the Griqua Town Hills or of the Doornberg. The jasper fragments have been found on Jackal's Post, Kain's Vlakte, and Rhenoster Valley along the Philipstown border at about the 3,800 foot contour, and even at Potfontein Station at over 3,900 feet.

[1] Ann. Report Geol. Comm. for 1906, pp. 22, 61.

[2] Ann. Rep. Geol. Comm. for 1906, p. 23.

These jaspers are always in small fragments, but further north, in a lower terrace (about 3,500 to 3,600 feet), they are more numerous and larger, *e.g.*, Hopetown, Klip Fontein, Probeer Fontein, De Kalk, Rittel Mago, Blaauw Kop, etc.

It is evident that since the formation of the peneplain of the Kaap the Orange River has cut its gorge to a depth of nearly 800 feet below the level of the plateau. It is clear also that the drainage system at this early period was very different from that of the present day. For example, there is evidence to show that the Harts River came into existence subsequently, and it is very probable that both the Vaal and Orange Rivers had very different courses to those which they now possess.

The second terrace is found along the Orange River at an altitude of from 150 to 400 feet above the stream-level, approximately at the 3,600 foot contour. It is well developed in the northern portion of Hopetown.

This terrace commences at Hopetown, where it is a shelf cut in Dwyka and covered with a layer of gravels from 5 to 10 feet thick, capped by tufa; the deposit is here about 30 feet in thickness, and occurs at from 140 to 200 feet above the river, the terrace having a slight rise to the south.

The pebbles are quite different to those found along the Vaal River, and include quartzite, lydianite, and other indurated sedimentary materials, diabase, dolerite, and of more interest than any of the others, amygdaloidal basalt from the Stormberg beds of Basutoland and the Drakensberg.

Further downstream the shelf is cut both in Dwyka and in Pniel diabase and quartzite, but the river flows in a gorge of ever increasing depth, while the terrace maintains a nearly constant altitude.

On Slypsteen, Kameel Drift, Klip Fontein to Rittel Mago, the terrace is beautifully seen, forming an escarpment following the winding of the river at a distance of several miles. Pebbles of lydiamite and occasionally of brown jasper are abundant.

Just beyond Rittel Mago this terrace slopes down to another at a lower level, but west of Pampoen Pan the escarpment is repeated for a number of miles, *e.g.*, Uitluchtige Pan, Welgevonden, Vraai Plaats, and Kwartels Pan. The terrace at one time extended northwards to the foot of the Kaap, for it is still well marked around Dopper Fontein and south-east of Read's Drift, while outliers exist on Roode Kop, Paarde Kloof, and Blaauw Kop.

The diabase, Black Reef quartzites, Campbell Rand limestones, and the Dwyka tillite are cut to a flat, and into this peneplain the Orange River has sawn its channel, and now flows for a number of miles in a deep gorge, the width of the excavation varying according to the nature of the material it traverses.

It is remarkable to find on the summit of Blaauw Kop, which

is south of the river, gravels in which pebbles of brown jasper predominate.

Lower terraces are found along the Orange River, a most important one being about 3,400 feet above sea-level. It is well seen on De Kalk, Blaauw Fontein, Probeer Fontein, Mark's Drift, and Roode Kop, and again on the north bank of the Vaal River between Douglas and Mazel's Fontein.

Remains of terraces are found at intervals along the Orange River below Read's Drift. The shelves are cut in the Dwyka, and at the bends in the river are many fine sections showing the tillite capped with gravels and tufa, *e.g.*, Kalk Krantz, O. 376 C, Sand Drift, Uitdraai, etc. The altitude is commonly from 250-300 feet above the river. Pebbles of jasper predominate in these gravels, and on the south side of the Orange River diminish in size the further away from the river the deposits are traced.

A high level terrace no doubt extended along the area drained by the Brak River, for this tract of country has very little variation in altitude. The formations consist of the Dwyka resting upon pre-Karroo rocks, and subsequent denudation has tended to remove the covering of softer material and reveal the undulating surface of pre-Karroo sediments and volcanics.

Gravels are, however, found at a number of points along the tributaries of the Brak River, *e.g.*, Walthoorn's Kraal, Knapdaar (near Beer Vlei). The pebbles consist of lydianite and dolerite with quartzites (Karroo sandstones indurated by dolerite intrusions).

Diamonds have been found at various localities in the northern half of Hopetown; as a matter of fact, the first diamond discovered in South Africa was picked up on the farm De Kalk.

It is very probable that the gravels contain many diamonds, but curiously enough along the Orange River, with the exception of a few trifling patches, all the gravels are cemented by calcareous material, and converted into compact conglomerate.

XII. On Pans.

This area is characterized by the presence of numerous pans, which are generally more or less confined to the tracts occupied by the Karroo beds.

In a few cases, pans have been determined by the removal of the Dwyka tillite from basin-shaped hollows in the pre-Karroo rocks. A fine example of this is Swingel's Pan, due north of Beer Vlei. The pan itself is not large, and is surrounded on three sides by ridges of Pniel quartzites and diabases. On the extreme east the slope of the ground is gradual, and the formation consists of the Dwyka, through which project hummocks of diabase. The catchment area is aproximately 35 square miles,

Pans are numerous in the Dwyka covered northern portion of Hopetown. Sometimes they are shallow depressions in one of the old river terraces, *e.g.*, Blaauw Fontein and Blaauw Kop, at other times they are deeply sunk beneath the level of the surrounding country.

Such examples are Krantz Pan, Zout Pans Fontein, Zout Pan (Prieska), Valsch Pan, Vogelstruis Pan (near Leeuwberg), and Roode Pan (near Blaauw Kop). An important feature about several of these pans is that their north-western boundaries are abrupt escarpments capped with a thick deposit of calcareous tufa. Each terrace, as it can be called, becomes less marked as it is followed round the pan, and on the south-east the slope towards the depression is generally a gradual one. This precipitous feature on the north-west side of the pan is especially well marked in the cases of Krantz Pan, Vogelstruis Pan, and Roode Pan. The origin of these escarpments, which in some cases rise as much as 150 feet above the bottom of the pans, is apparently connected with the prevailing winds which blow from the north and north-west. The hard tufaceous deposit protects the Dwyka shales and tillite from erosion, but on the slopes of the escarpment the sedimentary material suffers rapid disintegration, and is carried to the opposite end of the pan by the action of the wind.

There is in consequence an accumulation of sand around the south-eastern edge of the pan, for example, in Dik Pan and Krantz Pan, while in the pan at Brakkies the sand forms small dunes.

A peculiarity to which attention has been called in last year's Report (p. 126) is the way in which the red colour is removed from sand which has been blown into the pans. This is well seen in the Roode Pan near Blaauw Kop; there is a gradual fading of the red tint of the floor across the pan from north to south, and on the latter side the wind-borne material is of very pale colour and forms a small dune.

There are quite a number of large pans located upon Dwyka or Ecca shales, for example, to the south-west of Strydenburg and again in the Government's Pan between that village and Paauwpan Station.

The latter is an elongated pan, averaging two miles across, with a length of about 16 miles; towards the south-west it widens out, becomes ill-defined, and merges into wide flats covered with a film of hardened clay.

The large pan at Strydenburg occurs adjacent to a sill of dolerite dipping in below the pan itself. The presence of this intrusion has doubtless been the determining factor in the formation of the depression.

Generally, pans excavated in Dwyka tillite yield brack or salt water, for example, the pan on Zout Pan Put (near Hopetown), Zout Pans Fontein, Zout Pan (Prieska), Blaauw Kop, Drie Hoek's Pan, Brak Pan (near Strydenburg), etc. In some of

the pans rain water will stand for a considerable period without becoming brack, but upon digging in the pan, salt water is obtained, *e.g.*, Dik Pan, Krantz Pan. This is due to the clayey and impermeable nature of the surface layers of the floor. Many of the pans, especially those situated upon Ecca beds, yield fresh water.

The Dwyka tillite is the chief source of the salt, for a large number of wells in that formation yield undrinkable water.

Through the gravitation of the sub-surface water towards depressions the saline material is leached out of the rock and concentrated in these hollows. This explains why the water in the pans is so frequently salt.

The wells along the Beer Vlei yield very bad water, a matter capable of ready explanation when it is noted that rocks of pre-Karroo age form hills to the north-east and south-west, and that the drainage from a wide area gravitates into this depression and escapes along a narrow channel at the western end of the vlei, where it is very probable that the Karroo floor is not at any great depth below the surface.

The Brak River and its tributaries yield water of fair quality as far down nearly as the T'Kuip Hills. In the lower part of its course the water is usually only drinkable within a certain period after rains, or in certain spots in its channel. For some distance above its junction with the Orange River the water is undrinkable.

The lower reaches of the Brak River being entirely in the Dwyka tillite area, the source of the saline matter is clearly the formation which the river traverses.

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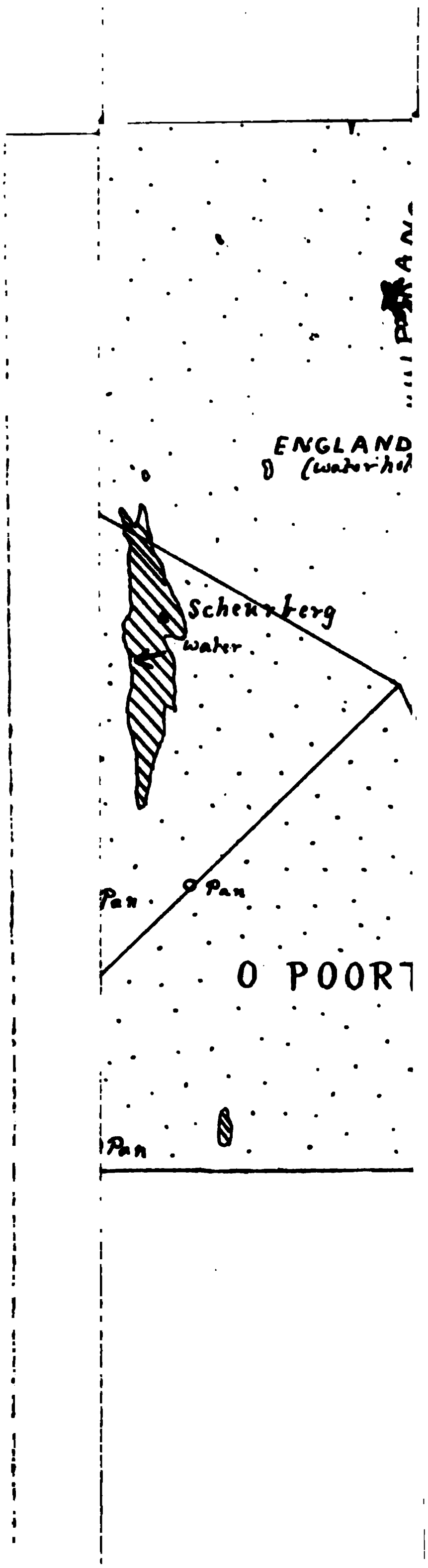
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